R&D for Silicon Forward Tracking at STAR

Zhenyu Ye @ UIC
STAR R&D meeting, BNL, 2/10/2014

華中師範大學
HuaZhong Normal University
UIC UNIVERSITY OF ILLINOIS AT CHICAGO

Outline

- Motivation
- Forward Tracking Concept
- R&D Plan

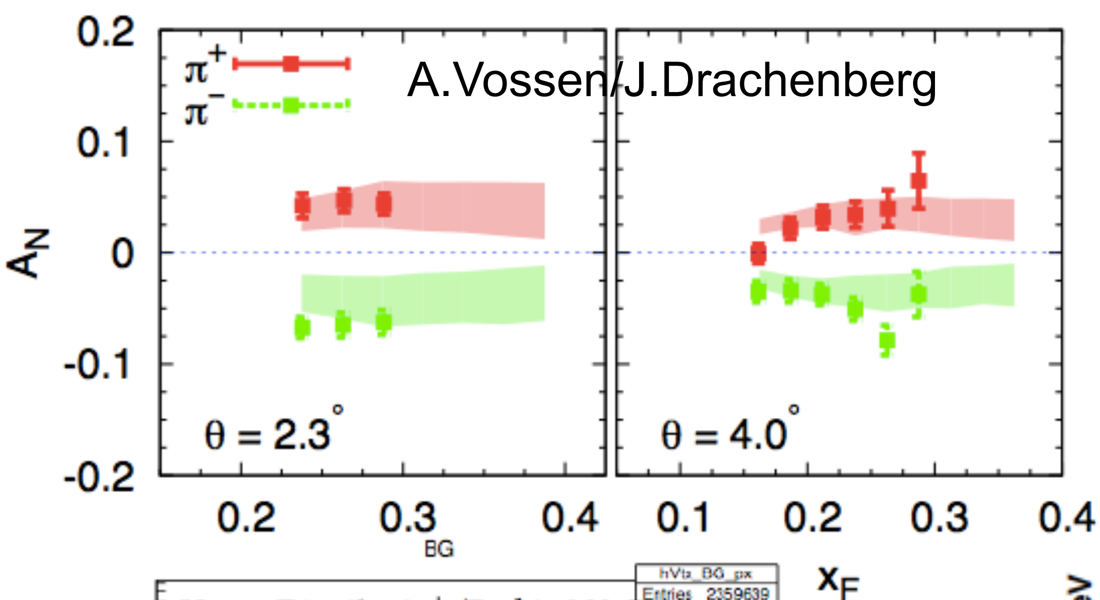
Key measurements for polarized pp scattering in 2021-2022

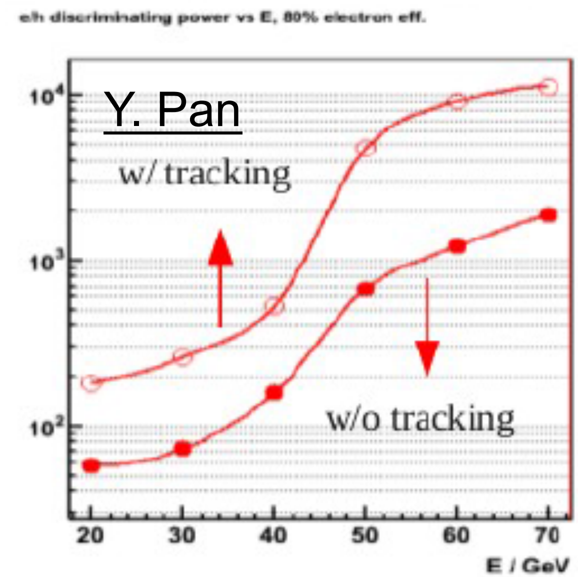
deliverables	observables	what we learn	requirements	comments/competition
HP13 (2015) **Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering.**	A_N for γ (?), $W^{+/-}$, Z^0, DY	Do TMD factorization proofs hold. Are the assumptions of ISI and FSI color interactions in pQCD are attractive and repulsive, respectively correct	high luminosity trans pol pp at √s=500 GeV DY: needs instrumentation to suppress QCD backgr. by 10^6 at 3<y<4	A_N DY: >=2020 might be to late in view of COMPASS A_NW,Z: can be done earlier, i.e. 2016
HP13 (2015) and flavor separation	A_N for γ, charged identified(?) hadrons, jets and diffractive events in pp and pHe-3	underlying subprocess causing the big A_N at high x_f and y	high luminosity trans pol pp at √s=200 GeV, (500 GeV jets ?) He-3: 2 more snakes; He-3 polarimetry; full Phase-II RP	the origin of the big A_N at high x_f and y is a legacy of pp and can only be solved in pp what are the minimal observables needed to separate different underlying subprocesses
transversity and collins FF	IFF and A_{UT} for collins observables, i.e. hadron in jet modulations A_{TT} for DY	TMD evolution and transversity at high x cleanest probe, sea quarks	high luminosity trans pol pp at √s=200 GeV & 500 GeV	how does our kinematic reach at high x compare with Jlab12 A_{TT} unique to RHIC
flavour separated helicity PDFs polarization dependent FF	A_{LL} for jets, di-jets, h/γ-jets at rapidities > 1 D_{LL} for hyperons	$\Delta g(x)$ at small x $\Delta s(x)$ and does polarization effect fragmentation	high luminosity long. pol pp at √s=500 GeV Forward instrumentation which allows to measure jets and hyperons. Instrumentation to measure the relative luminosity to very high precision	eRHIC will do this cleaner and with a wider kinematic coverage
Searches for a gluonic bound state in central exclusive diffraction in pp	PWA of the invariant mass spectrum in $pp \rightarrow p'M_Xp'$ in central exclusive production	can exotics, i.e. glue balls, be seen in pp	high luminosity pp at √s=200 GeV & 500 GeV full Phase-II RP	how does this program compare to Belle-II & PANDA

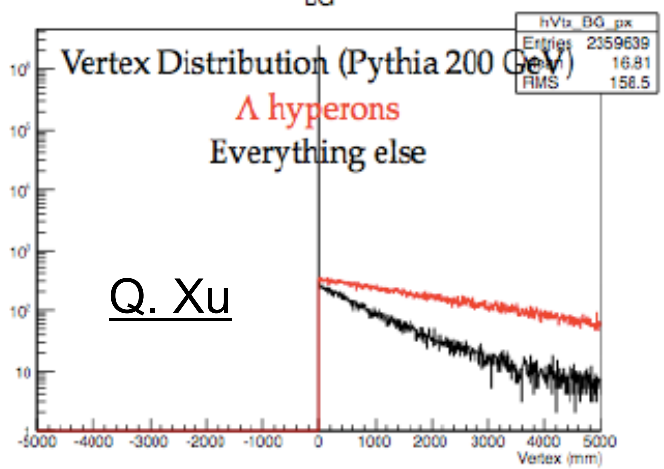
Key measurements for p↑A scattering in 2021-2022

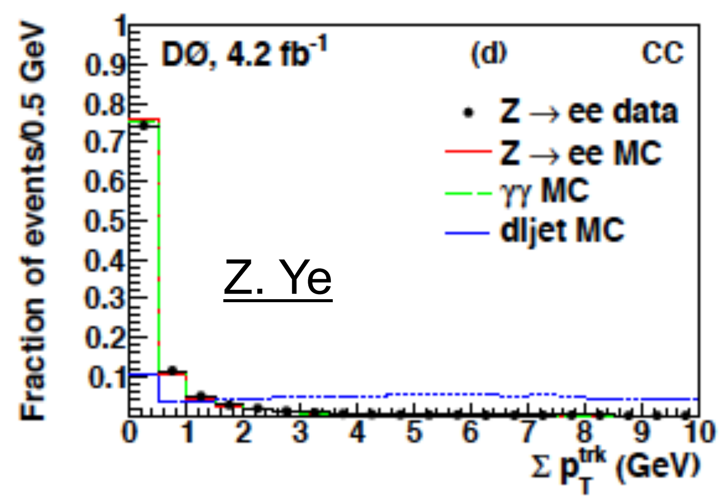
deliverables	observables	what we learn	requirements	comments/competition
DM8 (2012) determine low-x gluon densities via p(d) A	direct photon potentially correlations, i.e. photon-jet	initial state g(x) for AA-collisions	A-scan	LHC and inclusive DIS in eA eA: clean parton kinematics LHC wider/different kinematic reach; NA61
impact parameter dependent g(x,b)	c.s. as fct. of t for VM production in UPC (pA or AA)	initial state g(x,b) for AA-collisions	high luminosity, clean UPC trigger	LHC and exclusive VM production in eA eA: clean parton kinematics LHC wider/different kinematic reach
"saturation physics"	di-hadron correlations, γ-jet, h-jet & NLO DY, diffraction pT broadening for J/Ψ & DY -> Q_s	is the initial state for AA collisions saturated measurement of the different gluon distributions CNM vs. WW	capability to measure many observables precisely large rapidity coverage to very forward rapidities polarized pA A scan	complementary to eA, tests universality between pA and eA
CNM effects	R_{pA} for many different final states K^0, p, K, D^0, J/Ψ, .. as fct of rapidity and collision geometry	is fragmentation modified in CNM heavy quarks vs. light quarks in CNM	A scan to tag charm in forward direction → μ-vertex	separation of initial and final state effects only possible in eA
long range rapidty correlations "ridge"	two-particle correlation at large pseudo-rapidity $\Delta\eta$	do these correlations also exist in pA as in AA	tracking and calorimetry to very high rapidities	interesting to see the √s dependence of this effect compared to LHC
is GPD E_g different from zero	A_{UT} for J/Ψ through UPC Ap↑	GPD E_g is responsible for L_g→ first glimpse		unique to RHIC till EIC turns on
underlying subprocess for $A_N(\pi^0)$	A_N for π^0 and γ	underlying subprocess for $A_N(\pi^0)$ sensitivity to Q_s	good π^0 and γ reconstruction at forward rapidities	resolving a legacy in transversely polarized pp collisions

What a Tracker Do – Examples from Yesterday's pp/pA meeting





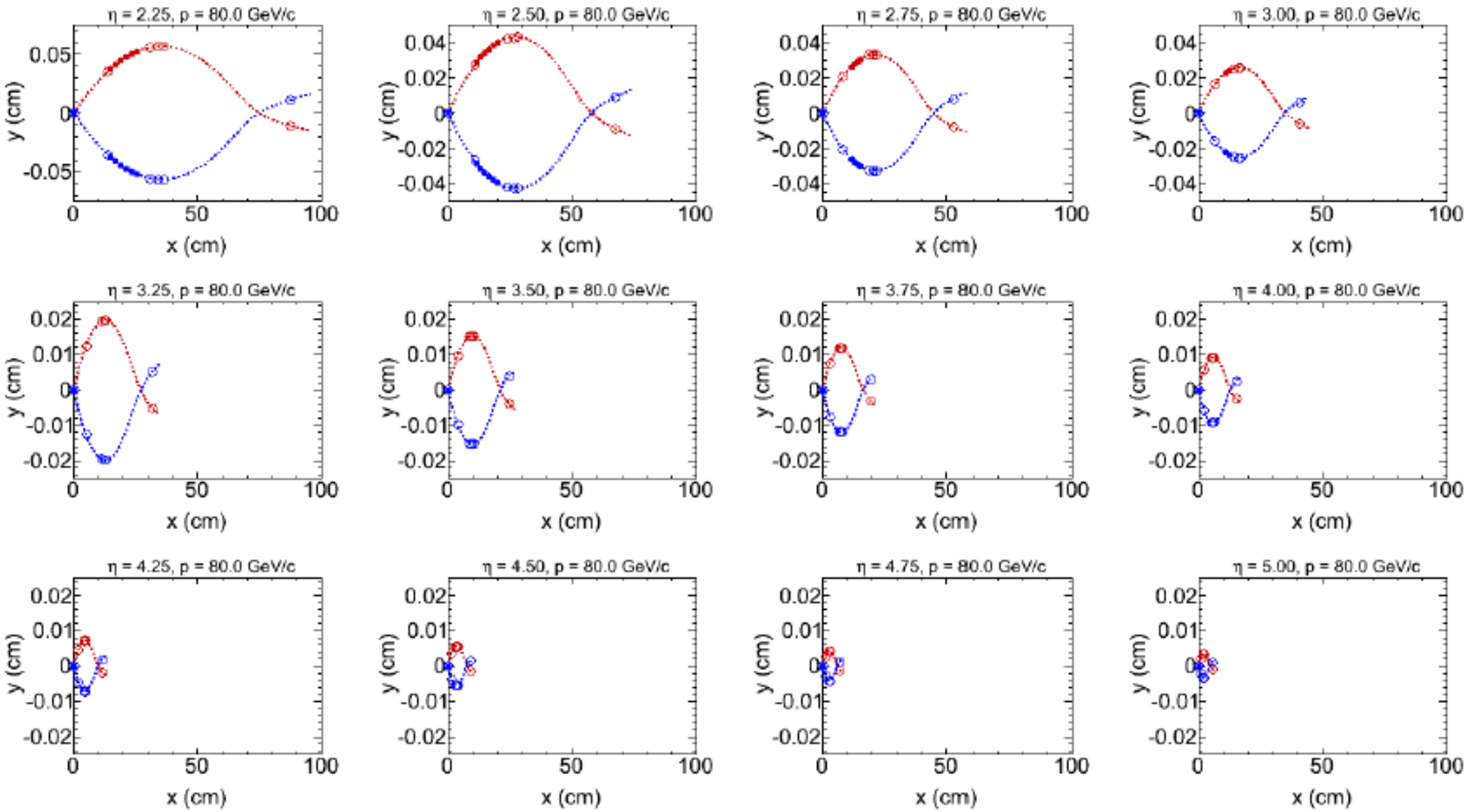




Forward Tracking Requirements

- pp/pA/ep/eA physics-driven requirements:
  - charge separation for π^+/π^-, di-hadron, Drell-Yan, J/psi
    ➔ low mass, good ϕ resolution
  - e/h discrimination for Drell-Yan, J/psi
    ➔ good ϕ resolution
  - e/γ discrimination for photon, Drell-Yan, J/psi
    ➔ low mass, high efficiency
  - vertex and charge sign for hyperon
    ➔ good eta and ϕ resolution
- AA physics-driven requirements:
  - event plane determination
    ➔ good ϕ resolution, large η coverage
  - centrality determination
    ➔ large η coverage
  - …

Why Silicon Ministrip Detector?

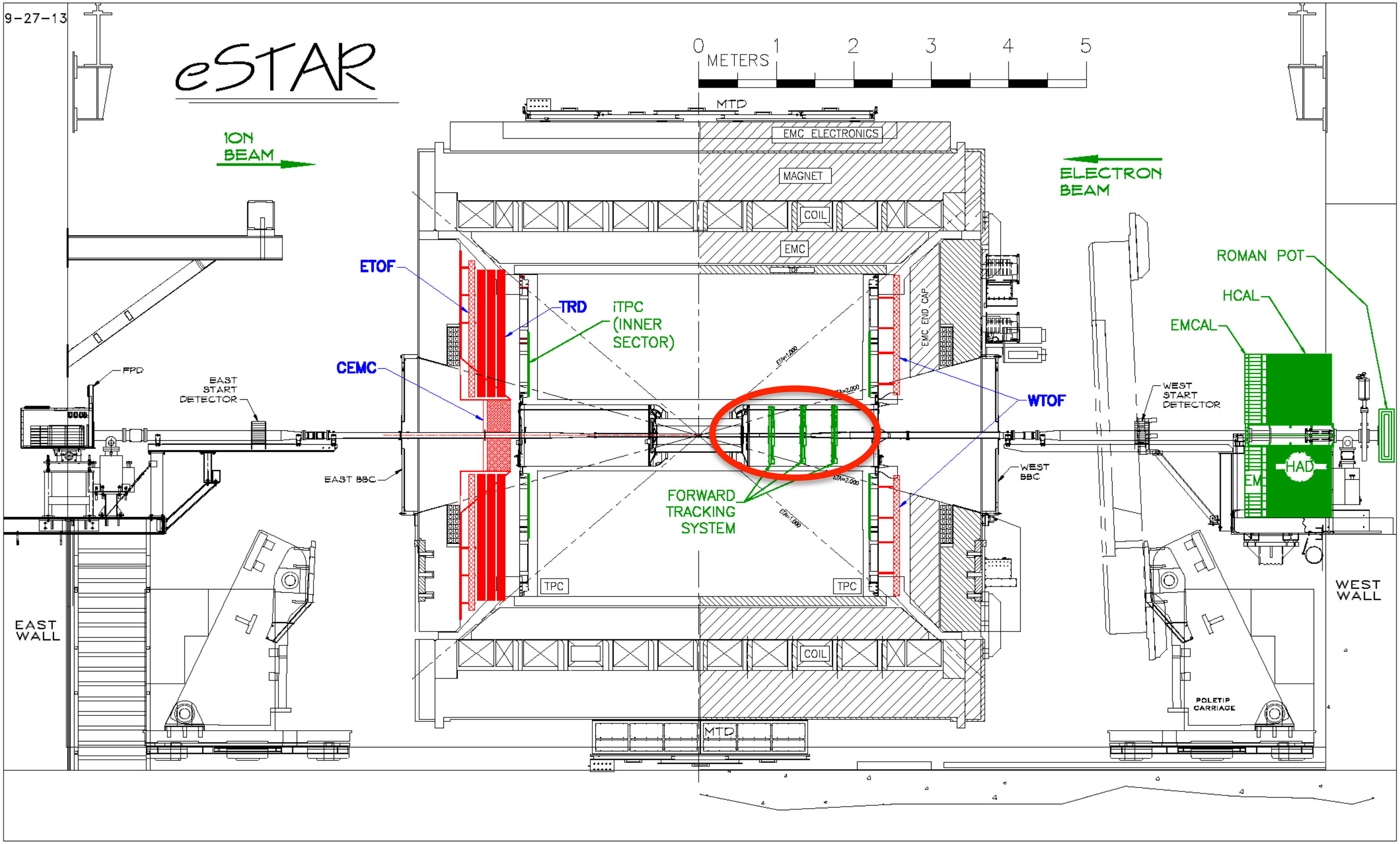


- Open symbols: hits at : z = 65 cm,145 cm,160 cm,170 cm, and 410 cm

filled symbols: FGT hits

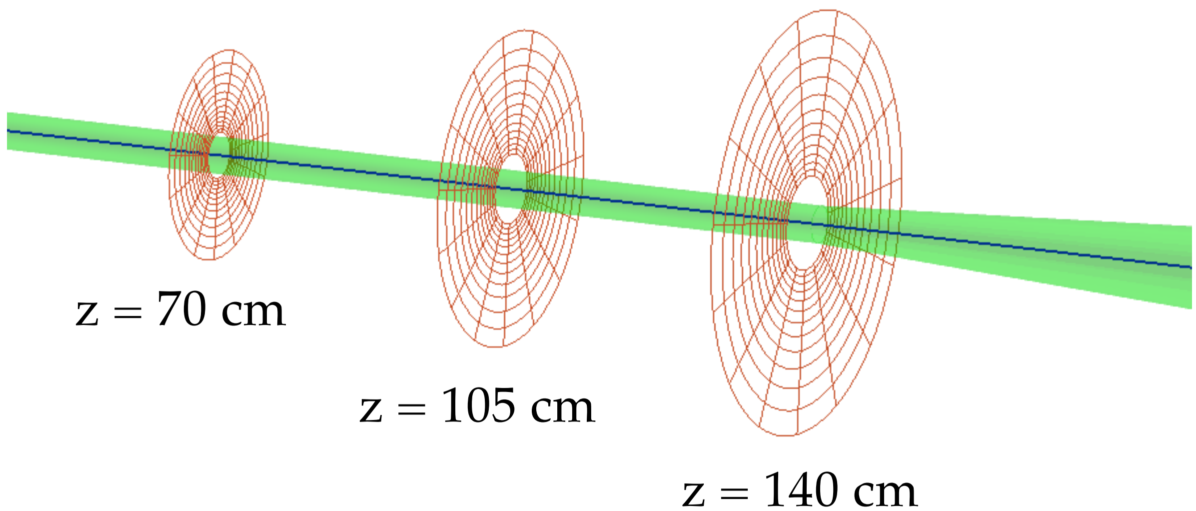
Z.Ye, STAR R&D meeting, 2/10/2014

Forward Tracking System



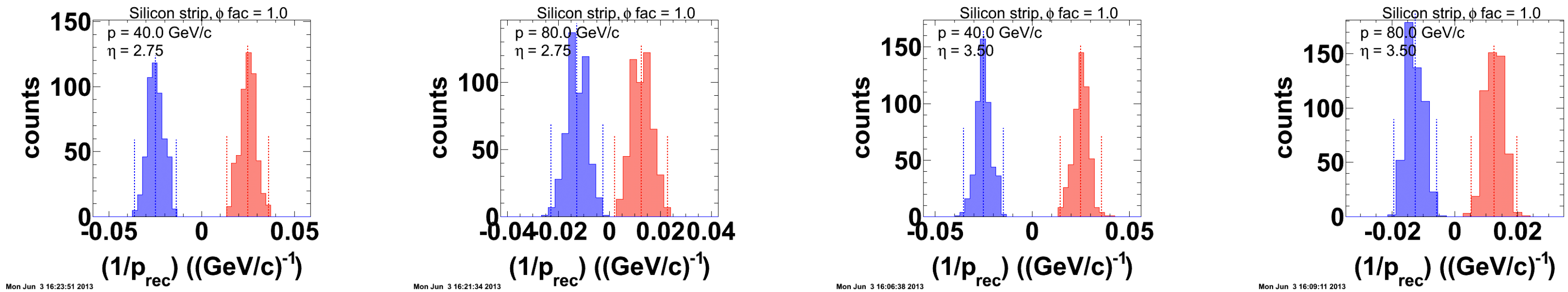
Z.Ye, STAR R&D meeting, 2/10/2014

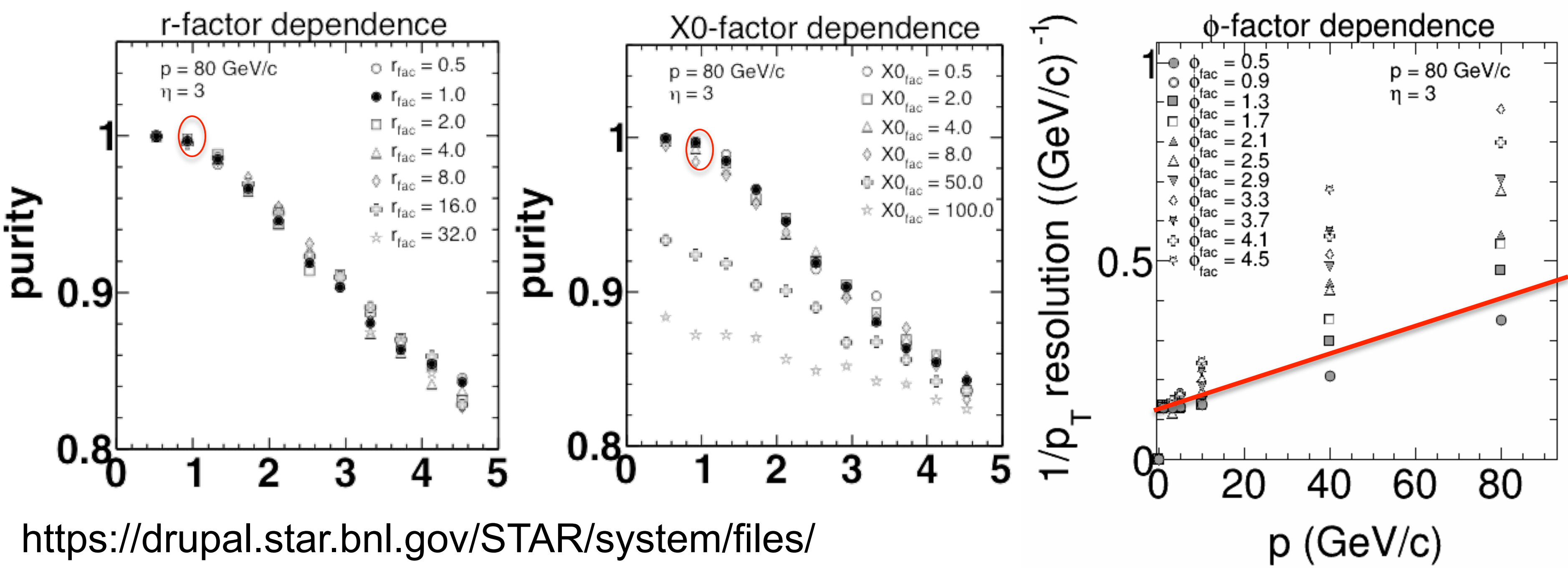
Three-Plane FTS



in [mm]	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}	r_{13}
plane 1	25.7	29.1	32.9	37.3	42.3	48.0	54.4	61.6	69.9	79.2	89.9	102.0	115.7
ϕ pitch	0.11	0.12	0.15	0.17	0.19	0.21	0.24	0.28	0.31	0.34	0.38	0.43	
plane 2	38.5	43.6	49.4	56.0	63.5	71.9	81.5	92.4	104.8	118.9	134.8	152.9	173.5
ϕ pitch	0.17	0.18	0.22	0.26	0.28	0.32	0.36	0.42	0.46	0.51	0.56	0.64	
plane 3	51.3	58.1	65.9	74.7	84.6	95.9	108.7	123.3	139.8	158.5	179.7	203.9	231.4
ϕ pitch	0.22	0.25	0.29	0.34	0.38	0.43	0.48	0.56	0.61	0.68	0.75	0.85	

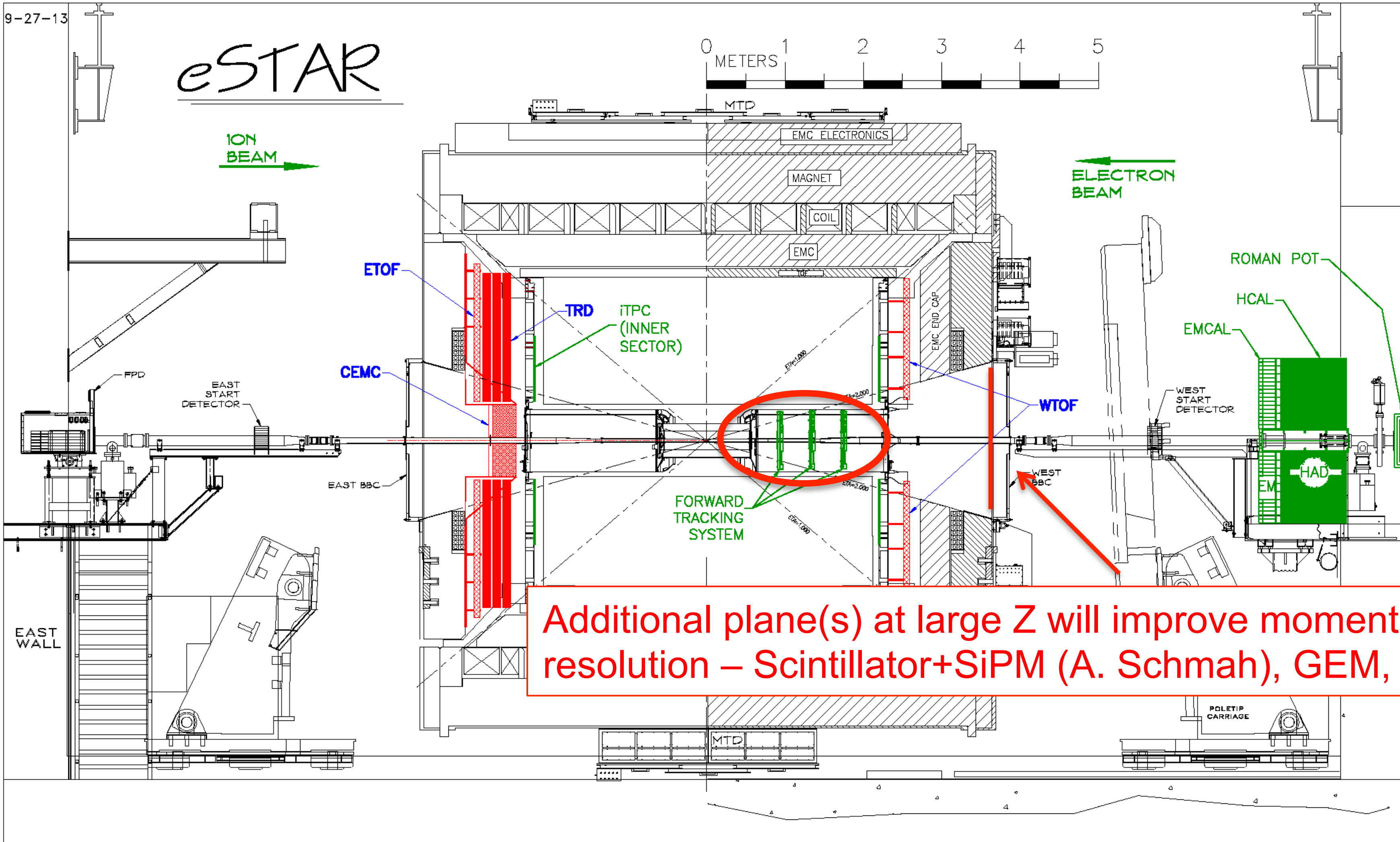
Performance Study (Alexander Schmah@LBNL)





https://drupal.star.bnl.gov/STAR/system/files/aschmah_eSTAR_Forward_Tracking_ULCA_8_2013_V4.pdf

Forward Tracking System



Additional plane(s) at large Z will improve momentum resolution – Scintillator+SiPM (A. Schmah), GEM, …

Z.Ye, STAR R&D meeting, 2/10/2014

R&D Proposal

STAR R&D Proposal December 2013

Prototyping for STAR Forward Tracking System

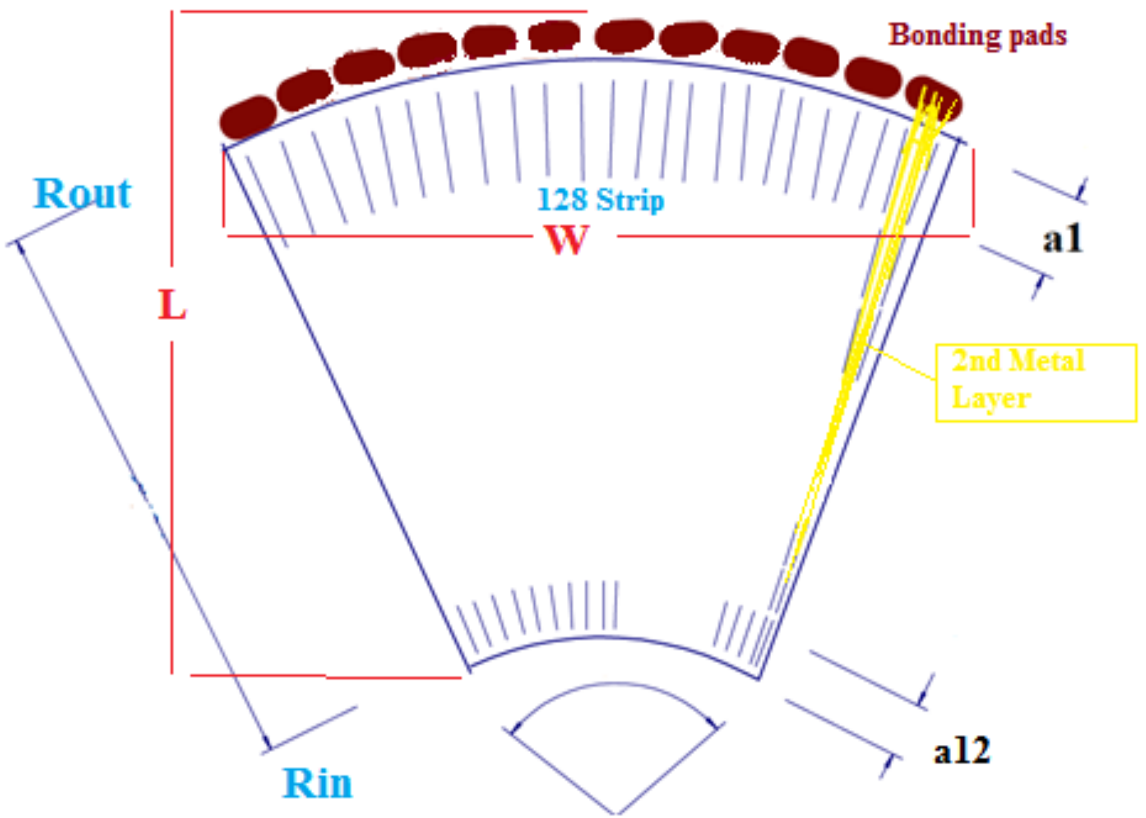
Zhenyu Ye (PI), Babak Abi, Yaping Wang
University of Illinois at Chicago

Alexander Schmah
Lawrence Berkeley National Laboratory

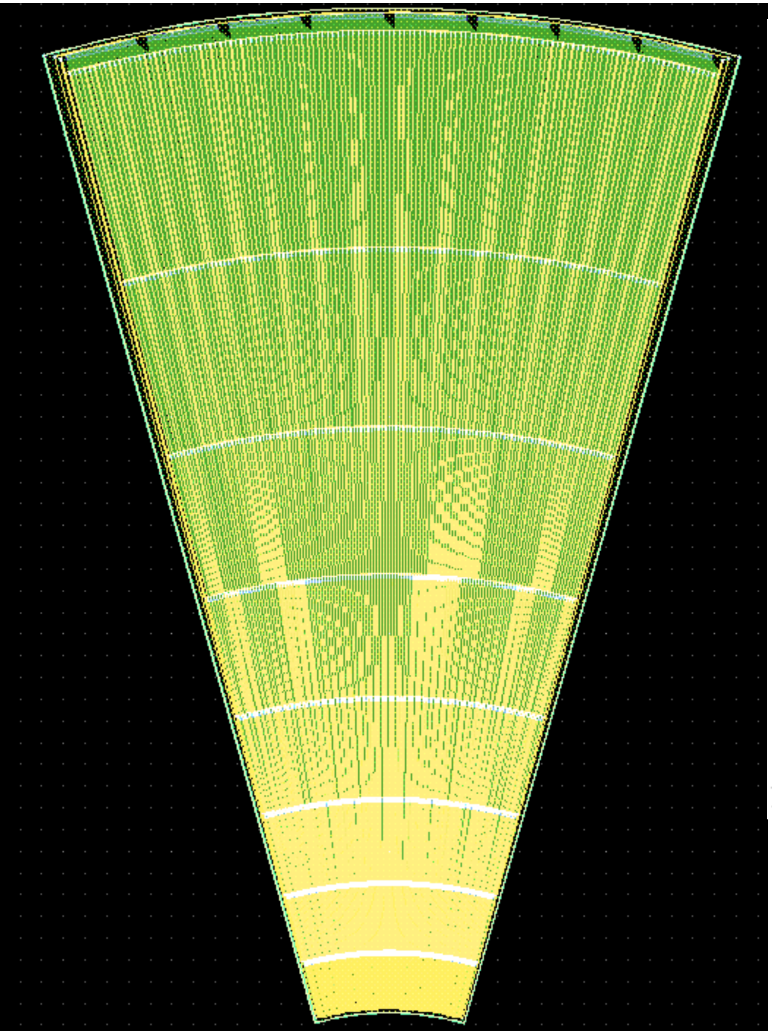
Abstract

We propose an R&D program for a forward tracking system (FTS) upgrade based on Silicon detector technology for the STAR experiment at RHIC. The proposed R&D efforts will be focused on development of Silicon Ministrip sensors and identification of suitable front-end readout chips for the FTS upgrade project. The goal is to assemble and test prototype modules to validate and optimize such a Silicon-based FTS design for future STAR physics programs.

Structure of Prototype Module



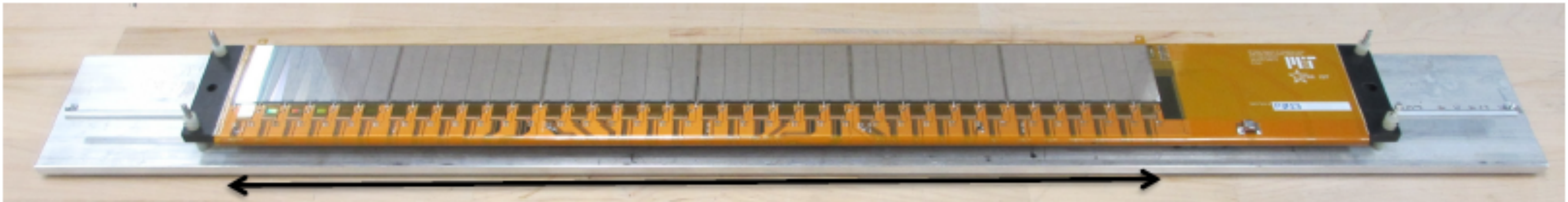
Sensor Mask Design (Babak Abi@UIC)



1. Layer **1** for Al layer at back-plane .
2. Layer 2 for N++ Implant at tailplane.
3. Layer 3 for N-Implant.
4. Layer **5** for P-implant .
5. Layer 7 for Poly-Silicon for Bias resistor .
6. Layer 9 for Metal-layer 1 over SiO2 layer.
7. Layer 10 for Metal Via 1 layer 10 to connect P-implant to Poly-Silicon bias resistor .
8. Layer 13 Metal layer 2 for routing to Bonding Pads at edge of wafer.
9. Layer 14 for Metal Via 2 layer to Connect Metal-layer 1 to 2 .
10. Layer 19 for Passive (protection) layer as negative mask.

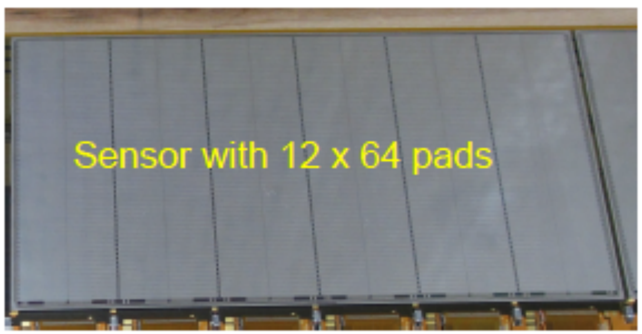
Simulation of electrical characteristics and layout optimization on-going

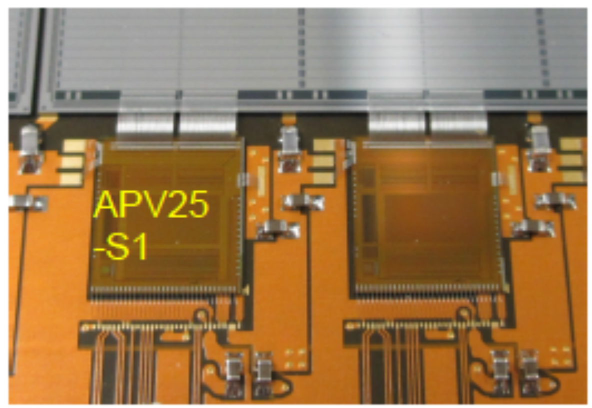
IST – Design Parameters



~50cm

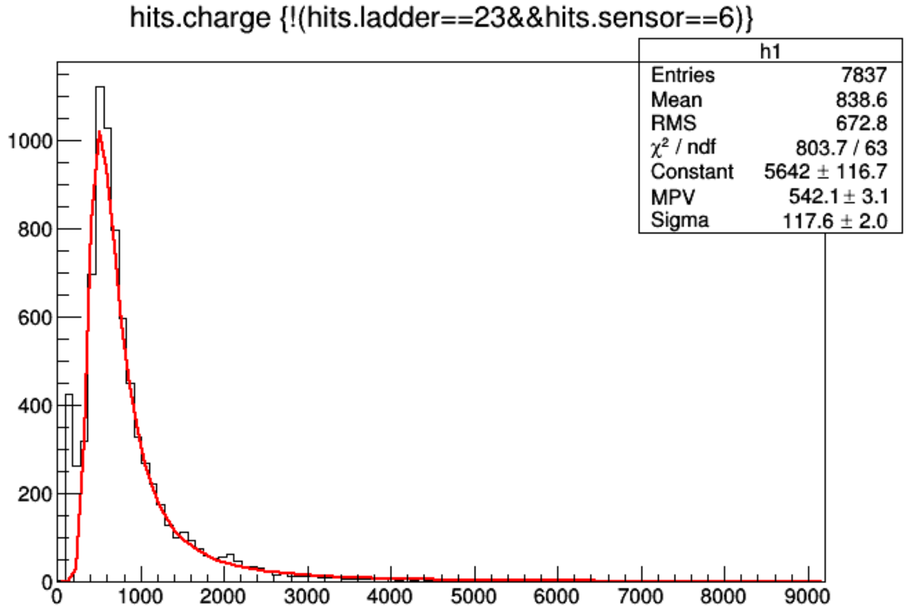
Radius	14cm
Length	50cm
ϕ-Coverage	2π
$\|\eta\|$-Coverage	≤ 1.2
Number of ladders	24
Number of hybrids	24
Number of sensors	144
Number of readout chips	864
Number of channels	110592
R-ϕ resolution	172μm
Z resolution	1811μm
Z pad size	6000μm
R-ϕ pad size	600μm

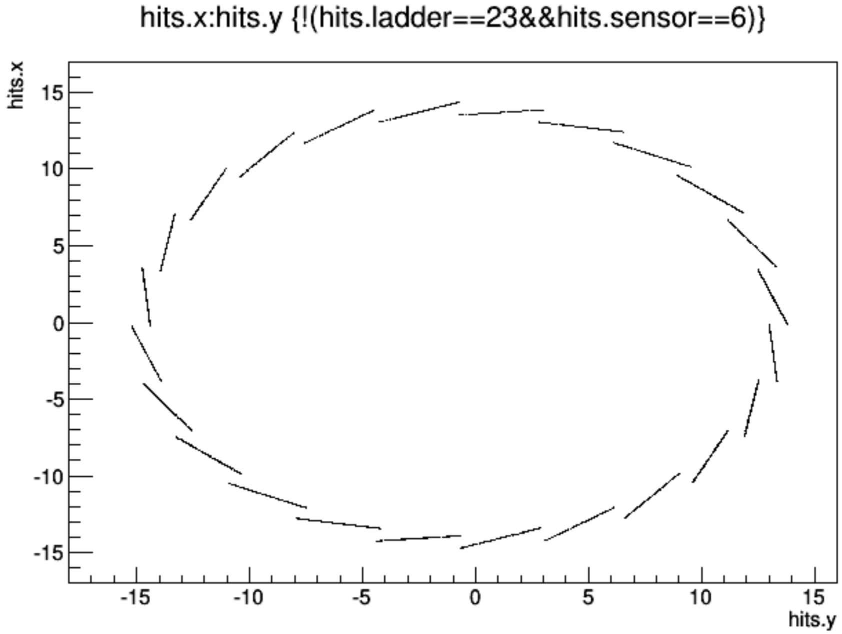




IST Stave =
carbon fiber ladder + cooling tube + kapton flexible hybrid + 6 silicon pad sensors + 36 APV25-S1 readout chips

HFT-IST Hits from Cosmic Ray Test (Yaping Wang@UIC)

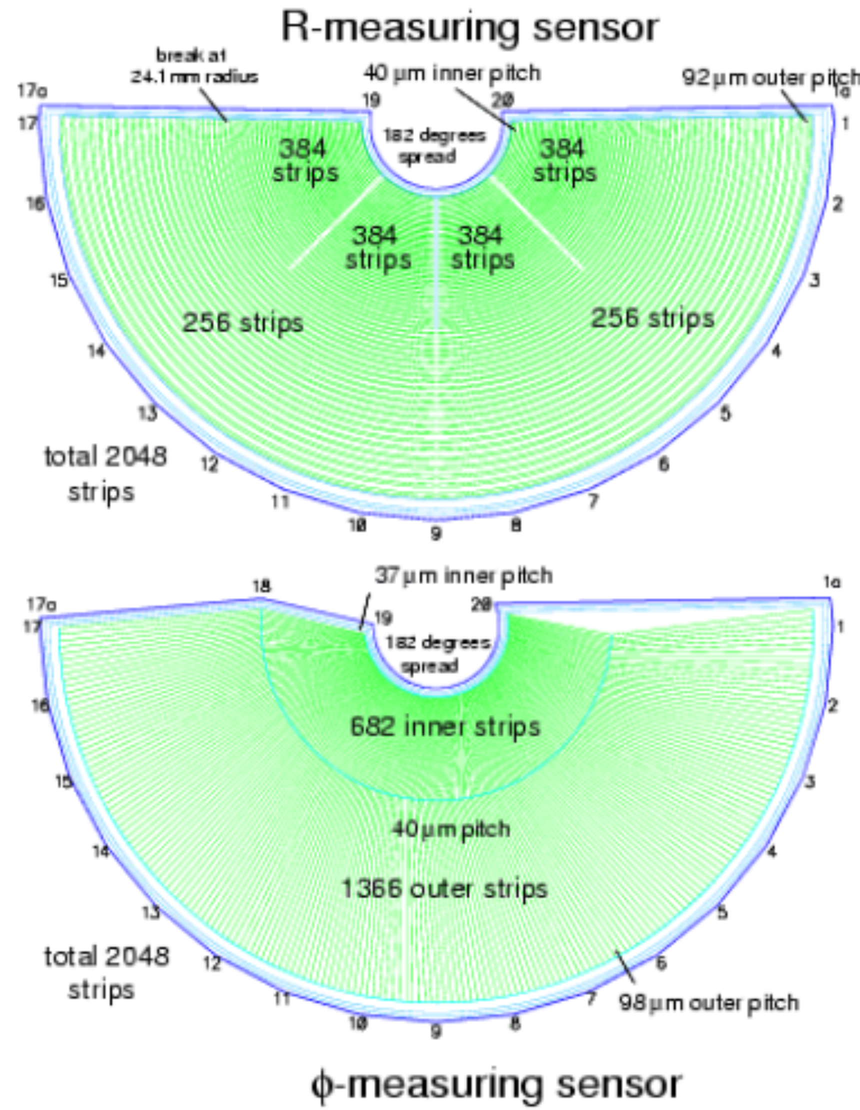




~96% active channels as of today

Requirements (2)

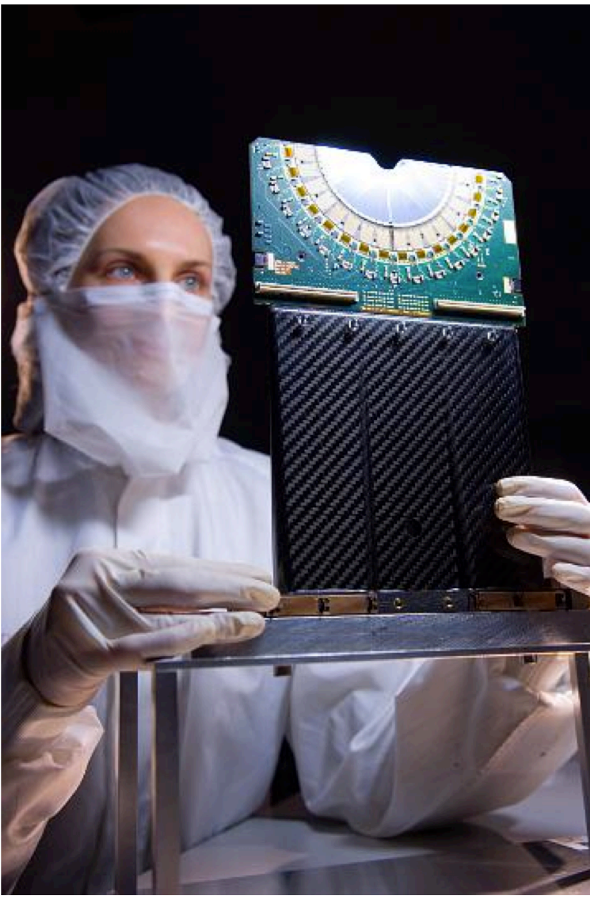
- Trigger (see talk by Niels Tuning)
  - **FAST** 2D (***rz***) and 3D (***rz*ϕ**) standalone tracking for **L1 Trigger**: **Choose RΦ geometry!**
  - Rejection of multiple interactions

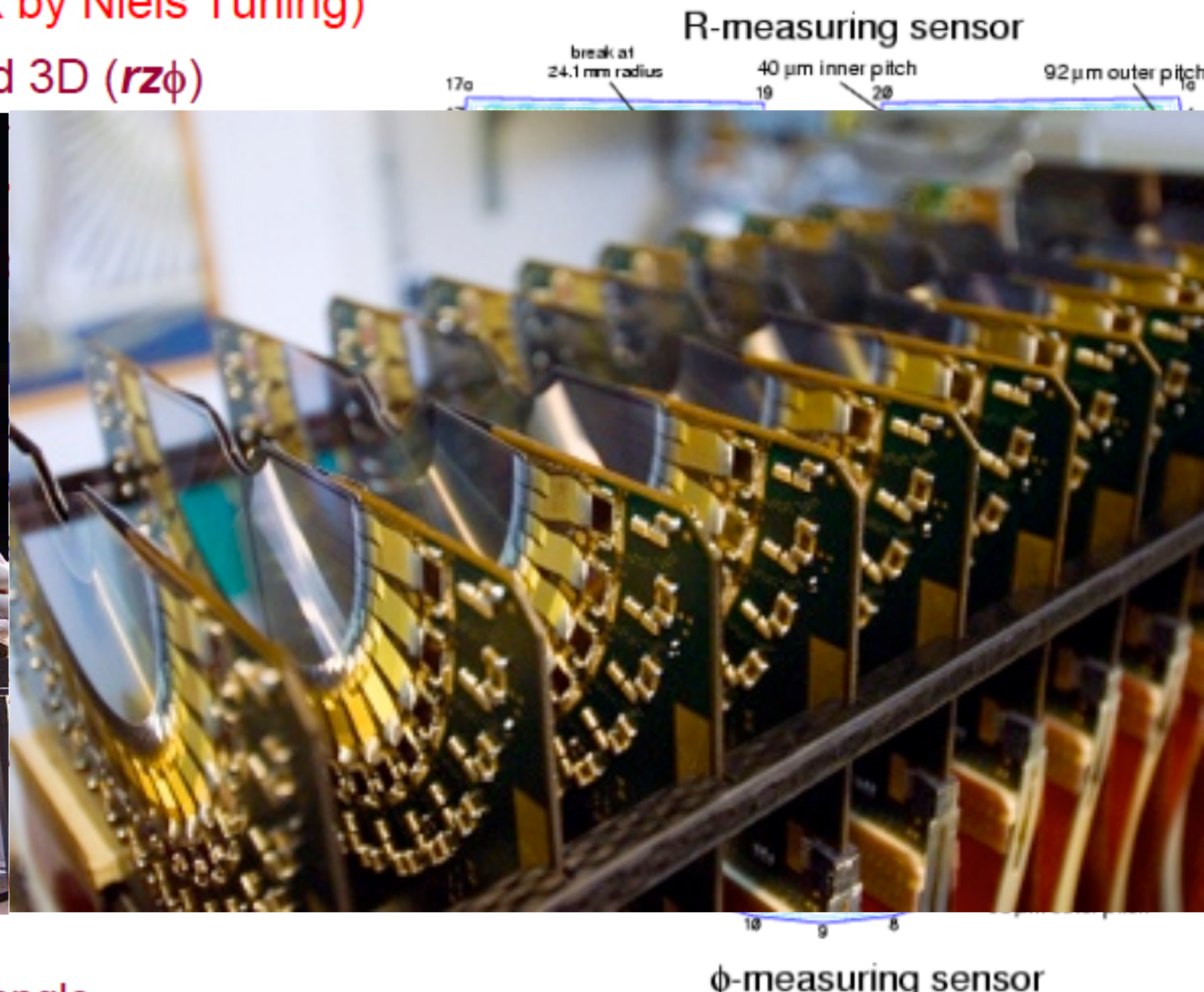


- **Baseline Sensor Design**
  - Sensors: 7mm>R>44mm (Active area 8mm to 43mm)
  - 182º angular coverage
  - R sensors
    - Pitch 40µm to 92µm
    - 45º inner, 90º outer sections
  - ϕ sensors
    - Pitch 37µm to 40µm and 40µm to 98µm
    - Double stereo angle

Requirements (2)

- Trigger (see talk by Niels Tuning)
  - **FAST** 2D (***rz***) and 3D (***rz***ϕ)



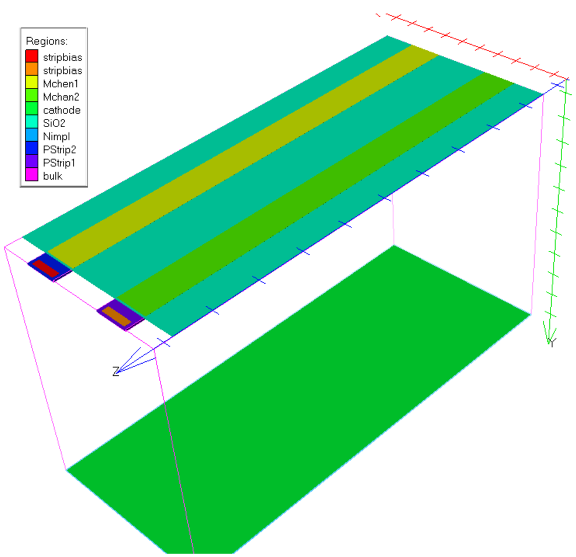


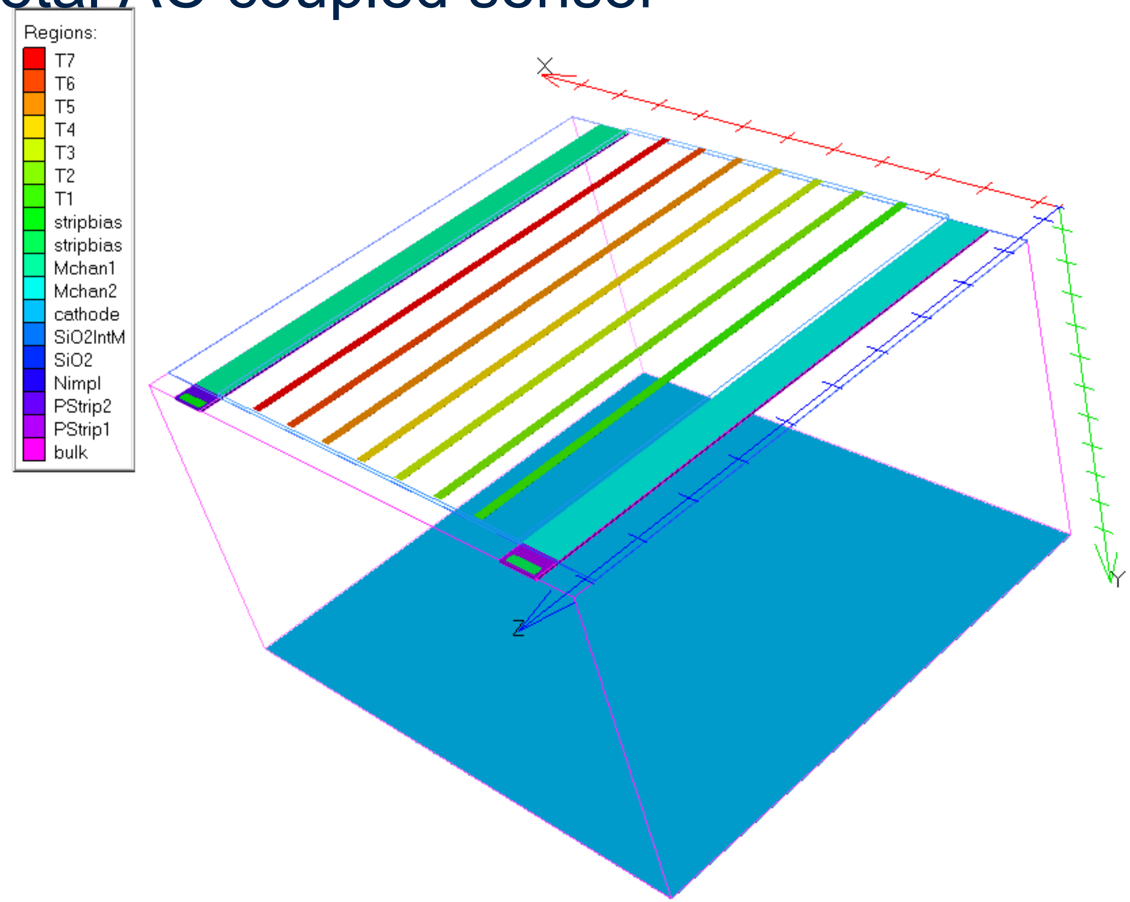
98µm

- Double stereo angle

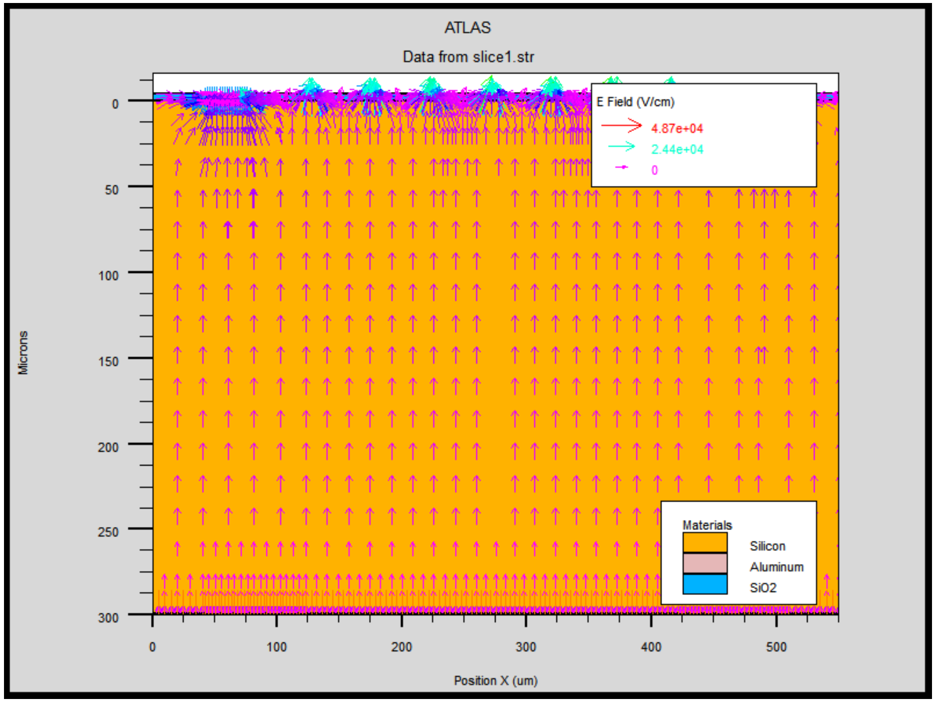
Sensor Characteristics from Simulation (Babak@UIC)

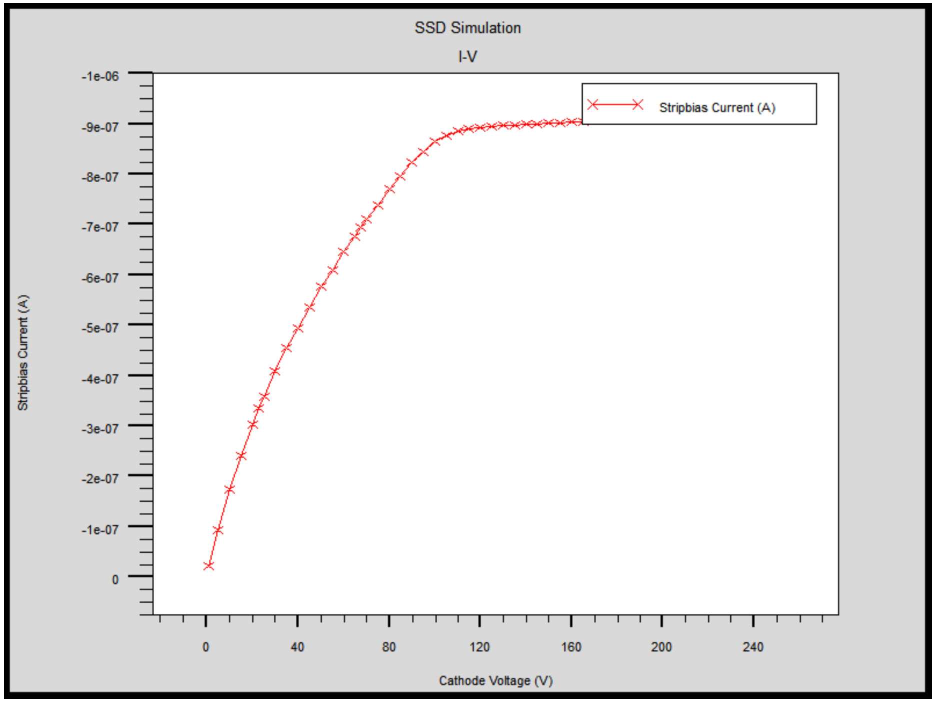
- Simulation by SILVACO (3D Semi-conductor device simulation)
- Single-sided double metal AC coupled sensor
- 300μ, 5KΩ/cm PinN





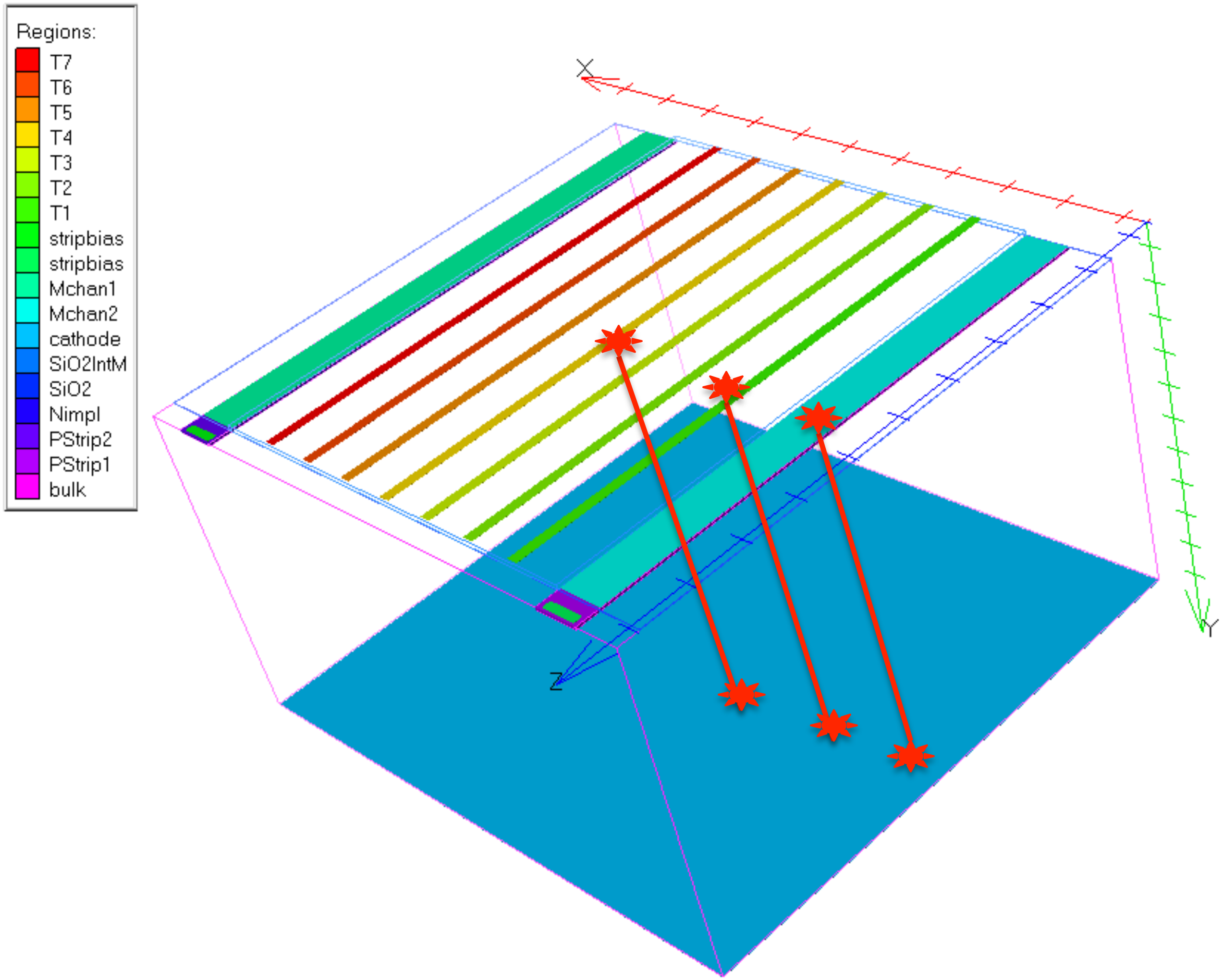
Sensor Characteristics from Simulation (Babak@UIC)



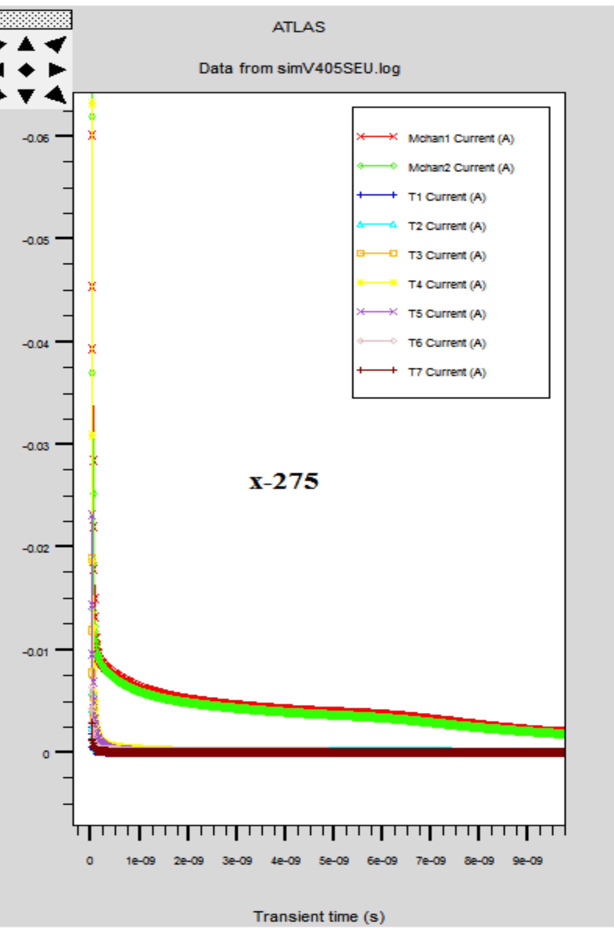


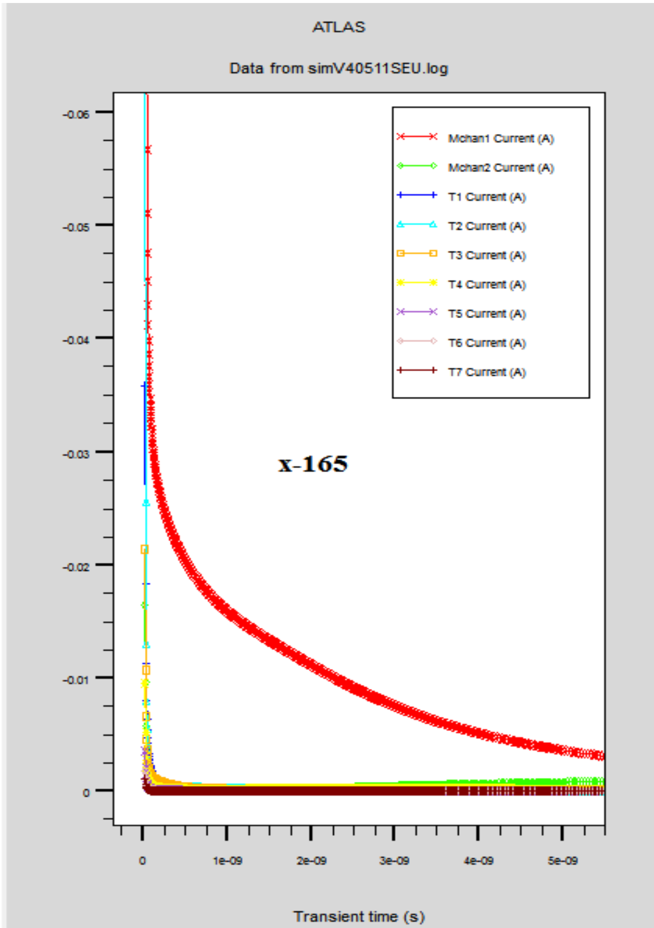
Good DC behavior, full depletion voltage ~ 100 V

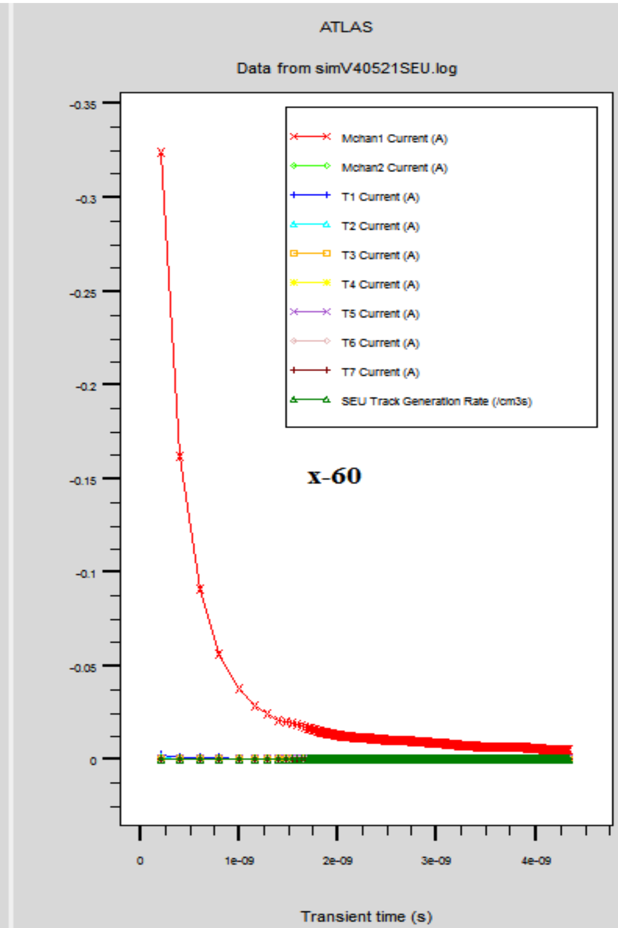
Sensor Characteristics from Simulation (Babak@UIC)



Sensor Characteristics from Simulation (Babak@UIC)







Good signal behavior with small amount of cross-talk

Quote from Micron UK

Single Mask Set Design/Engineering Qty 10 Mask Unit Price #$2500 CHIP ONLY cut probe tested	$25,000

Prototype from whole 6 inch wafer diced types Z1 for Q3-2014.	
Unit Price $4500 PROBE tested wafer ONLY	$4500
Additional $ 500/detector: Assembled on test frame: WIRE BONDED	$500
Total I-V.C-V ALPHA.NOISE/LIFE TESTS	per wafer

<u>Delivery</u>:	Design 2 months Prototypes 4 months from Design Approvals +/- 1 month contingency Mass Production : Over a period of 6 months. Completion end 2016. Call off rate to be agreed with customer +/- 1 month contingency

Quote from Hamamatsu

Single Mask Set Design/Engineering CHIP ONLY cut probe tested	$80,000
Prototype from whole 6 inch wafer diced types Z1 for Q3-2014.	$65,00 per chip

Funding Request for R&D

Table 1
Budget to develop Silicon sensors and to identify frontend readout chips

Silicon Sensor Mask Design and Procurement ($30k+$5.4k*8)	$73.2k
Frontend Readout Chip Procurement (CHF15*192)	$3.3k
PCB Design and Procurement	$20.0k
Electronics (DAQ, test setup and test run equipment)	$45.0k
Prototype Module Design and Assembly (with 26% overhead)	$20.2k
Machine and Electronics Shop (with 26% overhead)	$25.2k
Travel (with 26% overhead)	$6.3k
Shipment (with 26% overhead)	$6.3k
Total Direct Cost	$187.5k
Total Indirect Cost	$12.0k
Total Cost	$199.5k

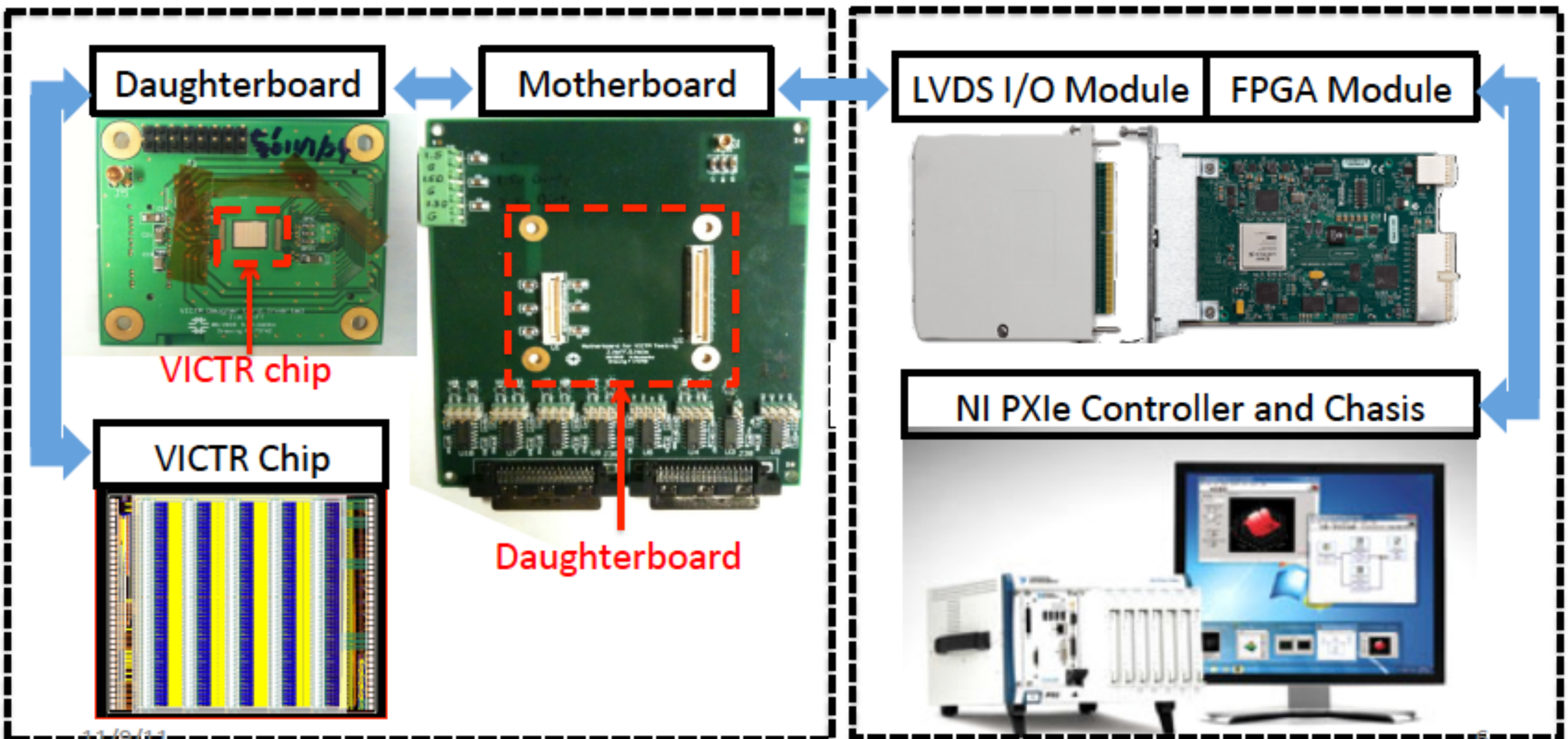
Table 2
Budget to develop Silicon sensors only (with APV readout).

Silicon Sensor Mask Design and Procurement ($30k+$5.4k*6)	$62.4k
Frontend Readout Chip Procurement (CHF15*192)	$3.3k
PCB Design and Procurement	$10.0k
Electronics (DAQ, test setup and test run equipment)	$10.0k
Prototype Module Design and Assembly (with 26% overhead)	$15.1k
Machine and Electronics Shop (with 26% overhead)	$18.9k
Travel (with 26% overhead)	$12.6k
Shipment (with 26% overhead)	$6.3k
Total Direct Cost	$124.7k
Total Indirect Cost	$10.9k
Total Cost	$135.6k

Micron UK-based

Test Stand

- Two customized PCB boards (passive components+LVDS/CMOS drivers).
- Nantional Instruments FlexRIO system (PC, on-board FPGA module, LVDS I/O adapter module) and Labview.



Funding Request for R&D

LHCb VELO Sensor Wafer by Micron UK

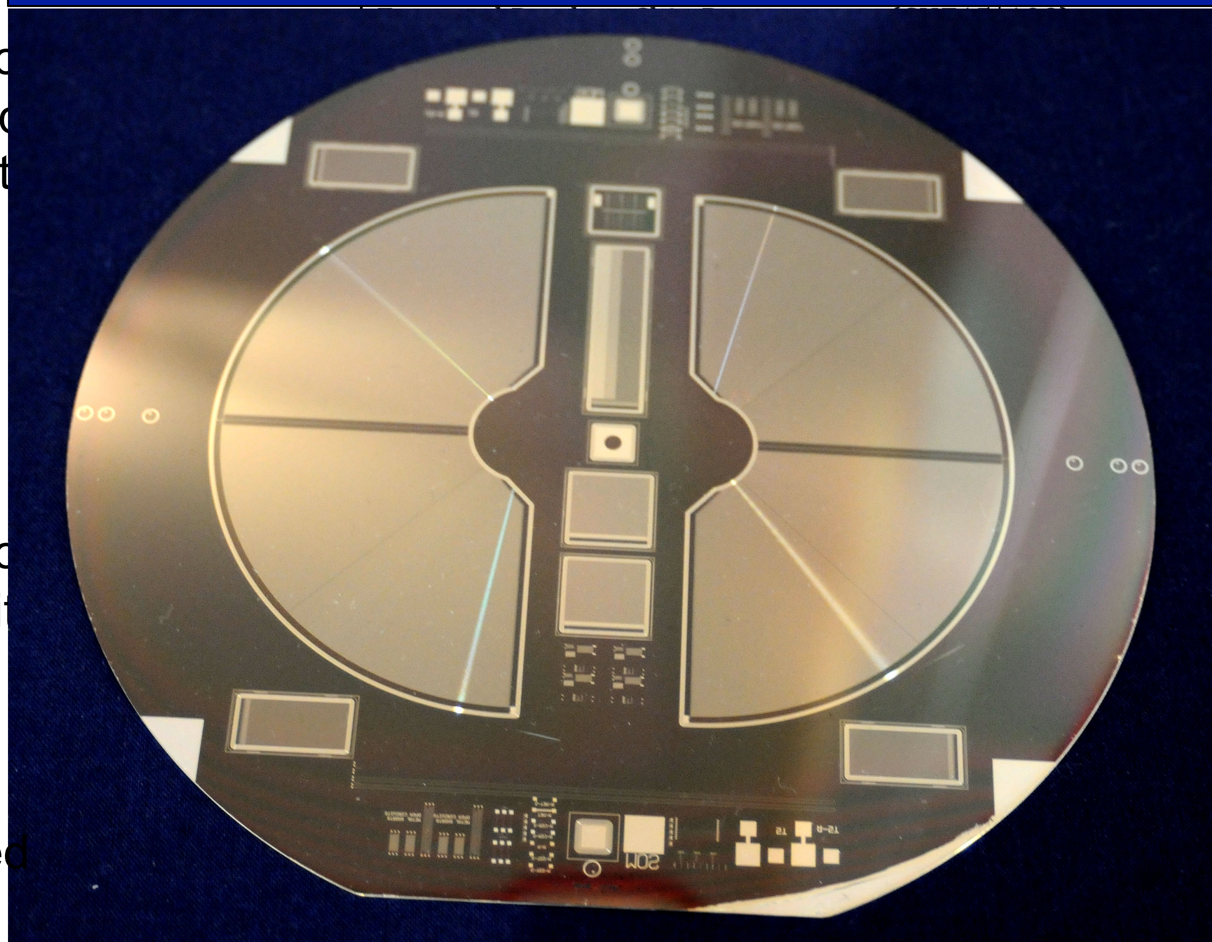


Table 1
Budget to develo
sensors and to ic
frontend readout

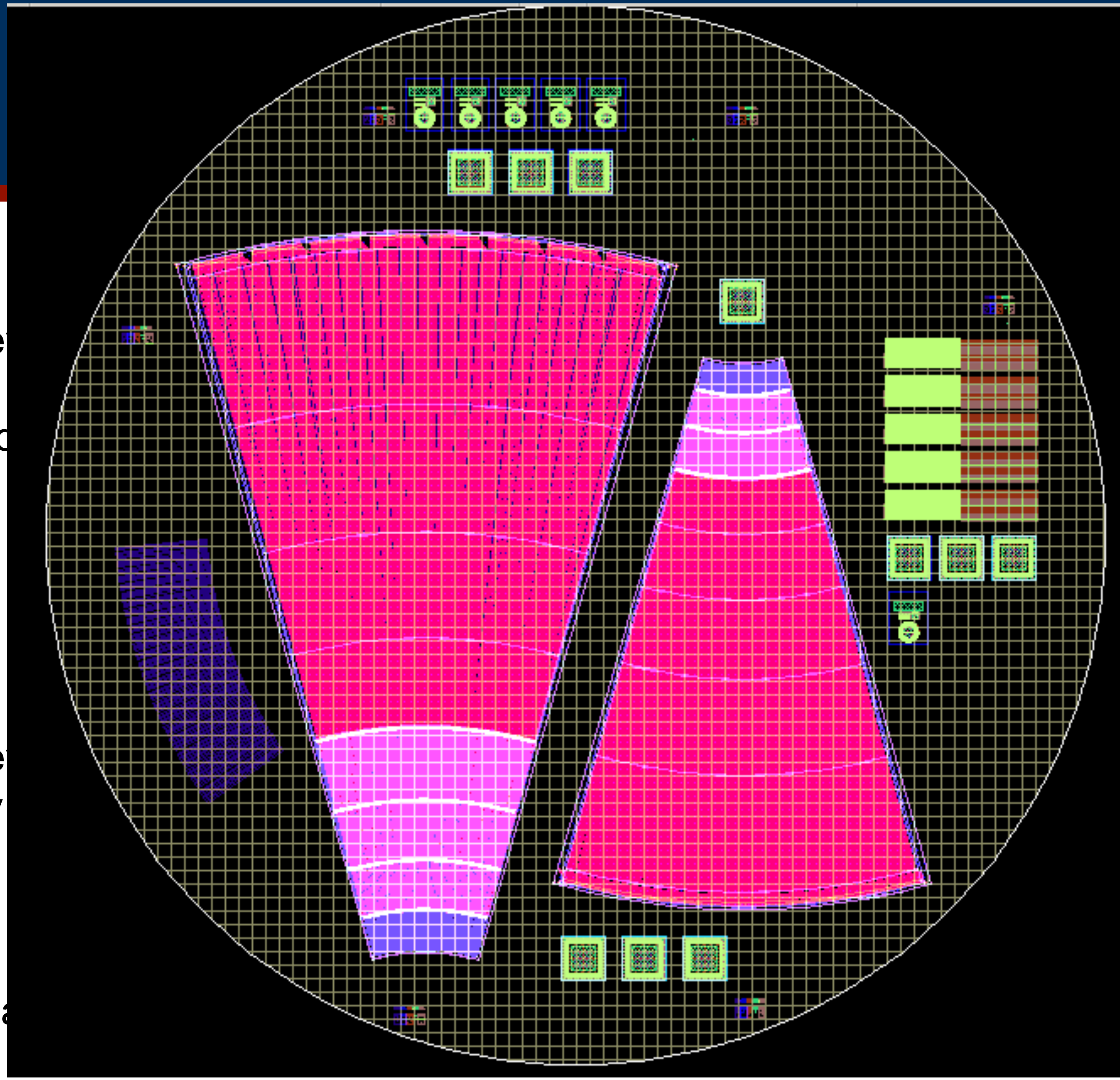
	$73.2k
	$3.3k
	$20.0k
	$45.0k
	$20.2k
	$25.2k
	$6.3k
	$6.3k
	$187.5k
	$12.0k
	$199.5k

Table 2
Budget to develo
sensors only (wi
readout).

	$62.4k
	$3.3k
	$10.0k
	$10.0k
	$15.1k
	$18.9k
	$12.6k
	$6.3k
	$124.7k
	$10.9k
	$135.6k

Micron UK-based

Table 1
Budget to de
sensors and
frontend reac



$73.2k
$3.3k
$20.0k
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Table 2
Budget to de
sensors only
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$62.4k
$3.3k
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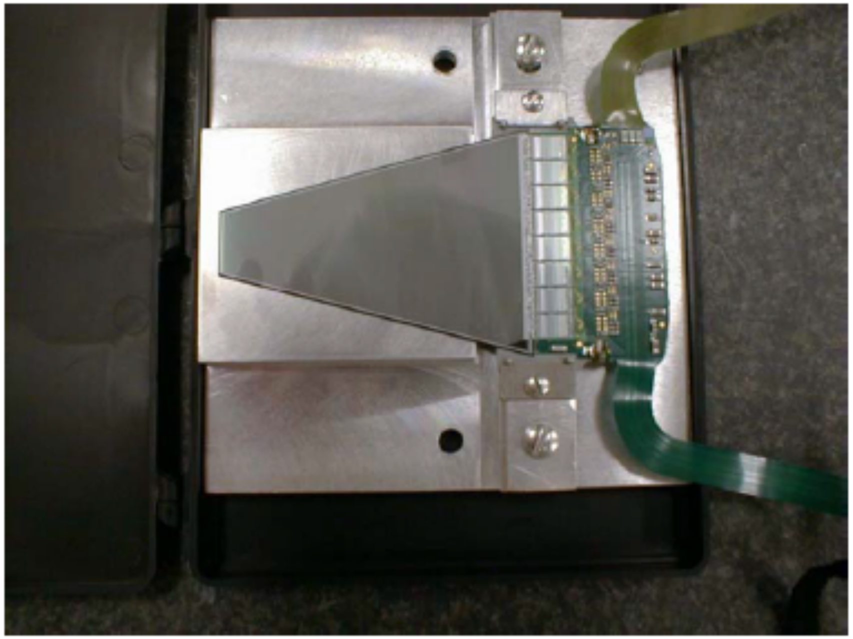
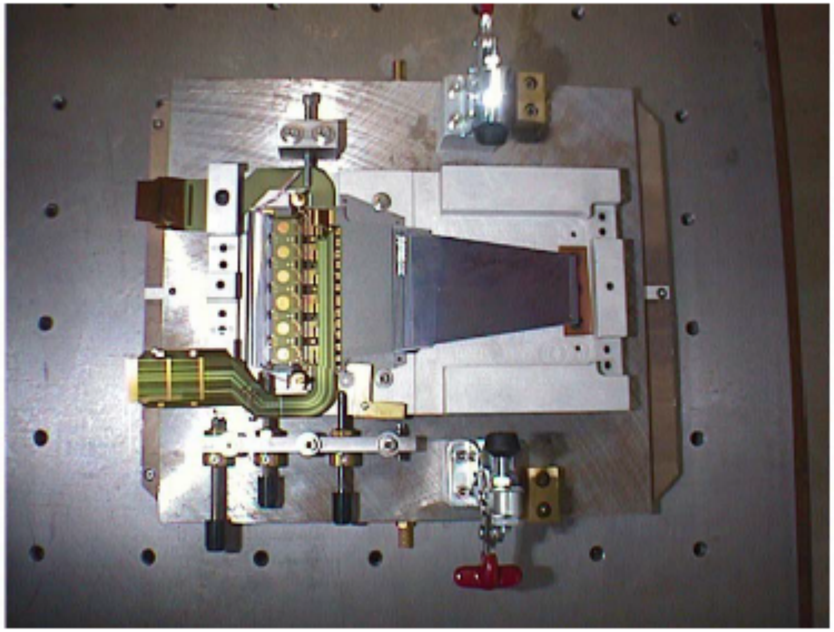
$10.0k
$15.1k
$18.9k
$12.6k
$6.3k
$124.7k
$10.9k
$135.6k

Micron UK-ba

Disk Detectors

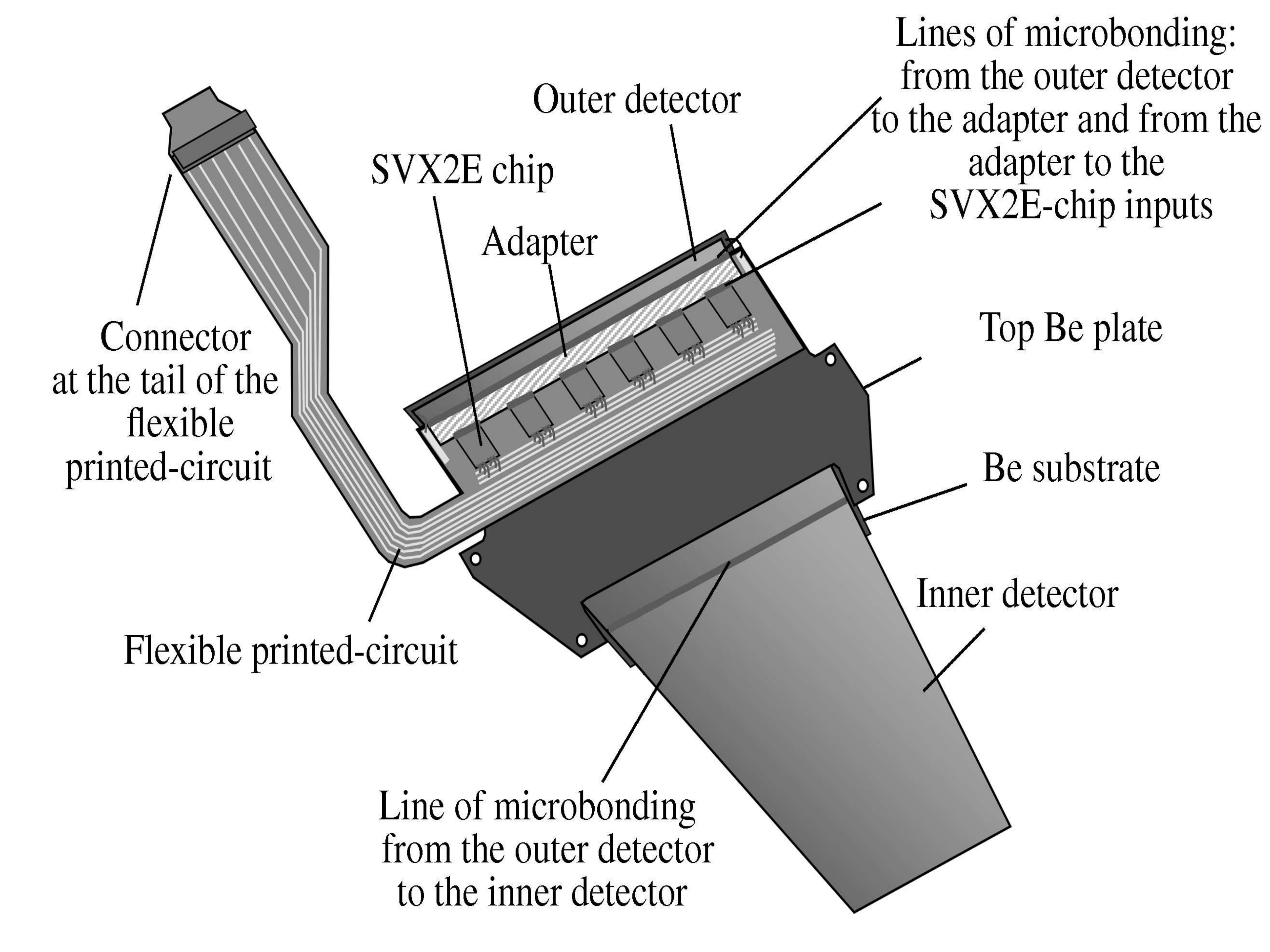


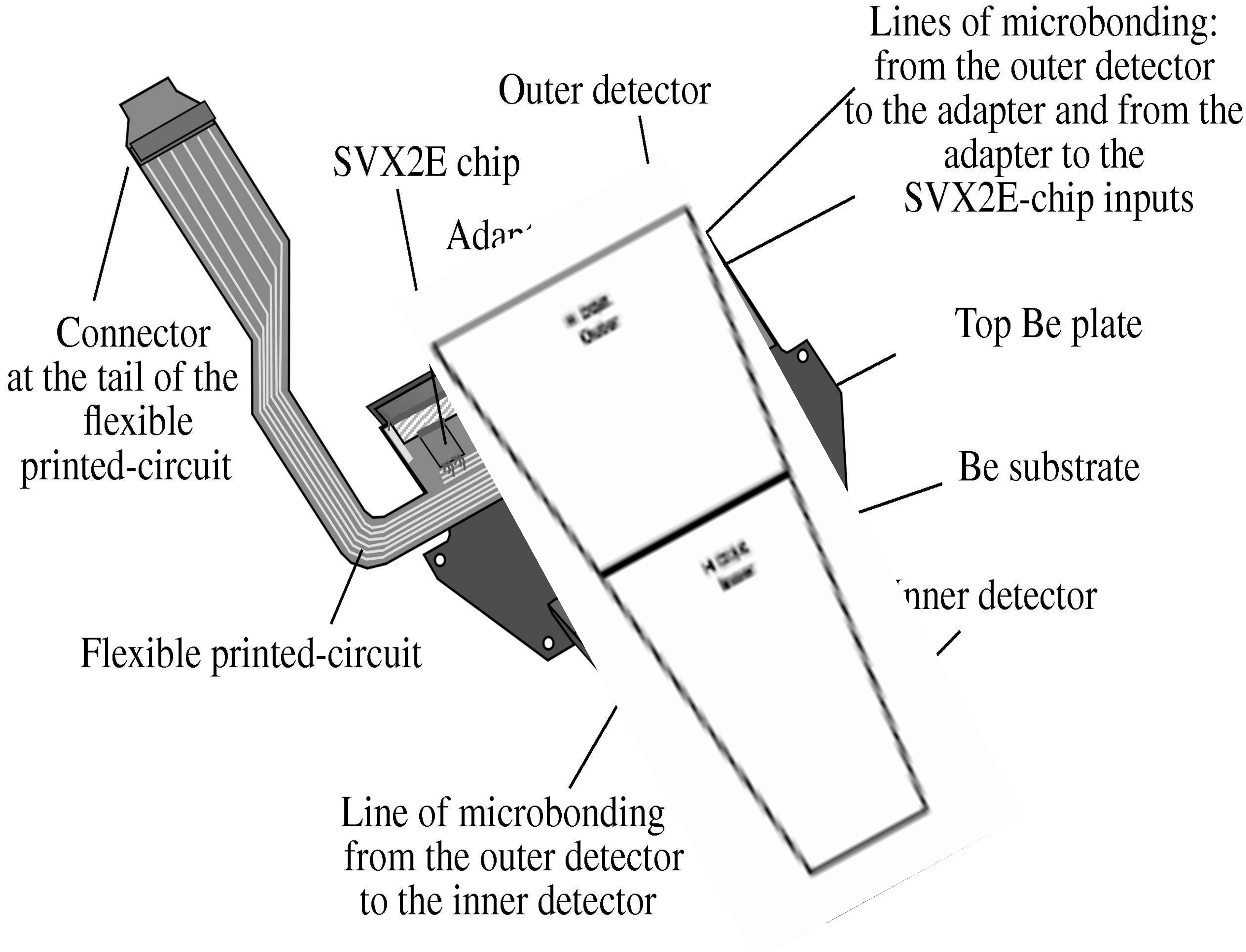
F-Wedge Detectors (144)
- 8+6 chip readout
- 2.6 cm < r < 10 cm
- Double sided wedges with $\pm 15^0$
- 50 μm (p-side), 62.5 μm (n-side)
- Variable strip length



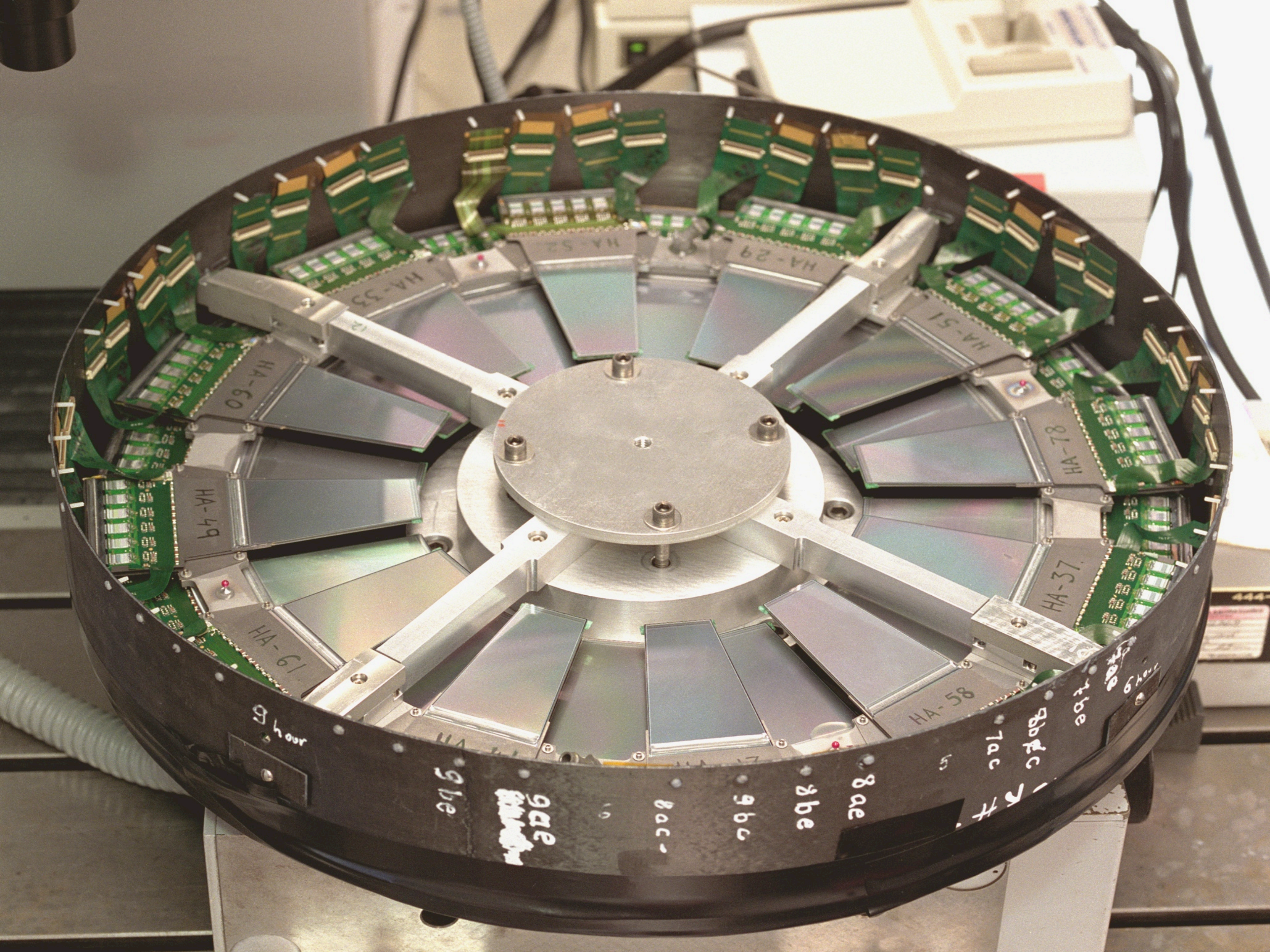
H-Wedge Detectors (384)
- 6+6 chip readout
- 9.6 cm < r < 23.6 cm
- Single sided glued back-to-back with $\pm 7.5^0$
- 40 μm (p-side) strip pitch
- 80 μm readout pitch
- Variable strip length

Cecilia Gerber, Fermilab


Lines of microbonding:
from the outer detector
to the adapter and from the
adapter to the
SVX2E-chip inputs
Outer detector
SVX2E chip
Adapter
Connector
at the tail of the
flexible
printed-circuit
Top Be plate
Be substrate
Inner detector
Flexible printed-circuit
Line of microbonding
from the outer detector
to the inner detector



Lines of microbonding: from the outer detector to the adapter and from the adapter to the SVX2E-chip inputs
Outer detector
SVX2E chip
Connector at the tail of the flexible printed-circuit
Top Be plate
Be substrate
Flexible printed-circuit
Line of microbonding from the outer detector to the inner detector


HA-52
HA-29
HA-51
HA-78
HA-37
HA-58
HA-61
HA-49
HA-60
HA-53
9 hour
9be
9ae
8ac
9bc
8be
8ae
7ac
9 hour

R&D Timescale and Deliverable

If proposal approved:

- Finalize wafer layout and place order (UIC) – Spring 2014
- Sensor characterization (Vendor/UIC) – Fall 2014
- Prototype and DAQ assembly (Fermilab/UIC) ~ Fall/Winter 2014
- Test the prototype performance (UIC) ~ 2015

Goal/Deliverable

- develop Slicon Ministrip sensor and identify suitable front-end readout chips, assembled on prototype modules
- Involve interested institutions to join these R&D efforts and look into electrical / mechanical with a full FTS system design in 2016

Backup

Previous Talks

Silicon Strip Option Discussion (Zhenyu Ye@UIC):

http://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20130423_3.pdf

https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20130829.pdf

https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20131015.pdf

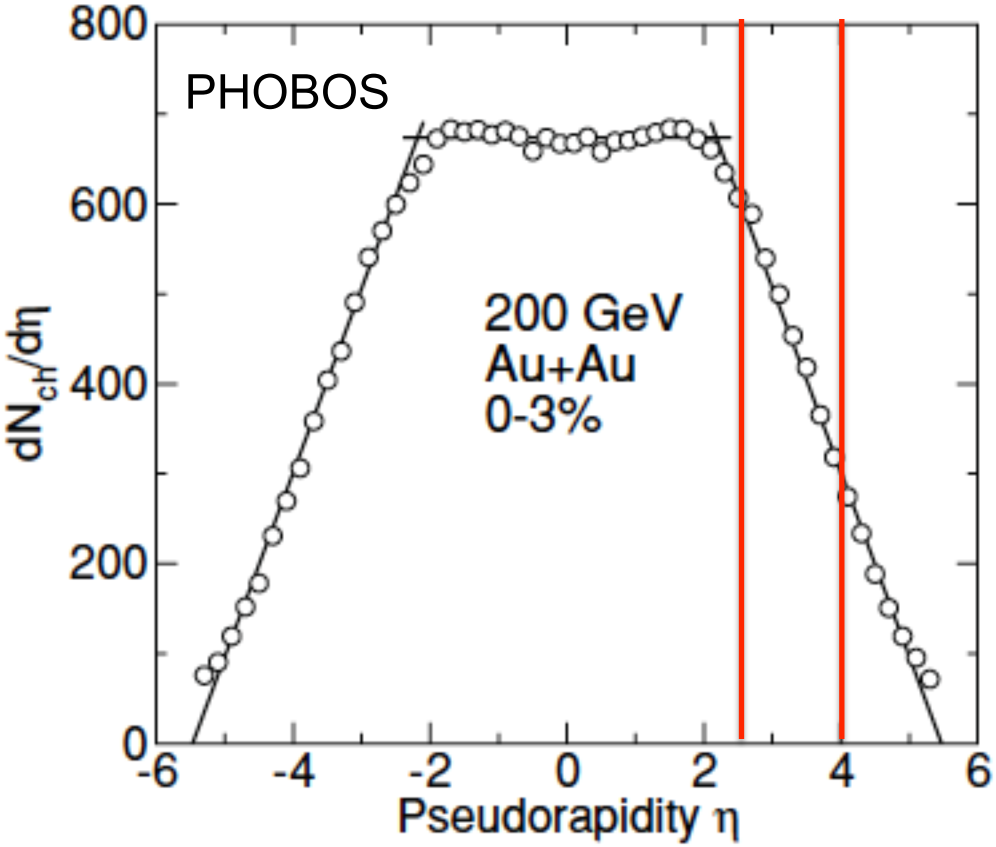
https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20140111.pdf

Simulation Discussion (Alexander Schmah@LBNL):

http://www.star.bnl.gov/protected/heavy/aschmah/Presentations/aschmah_eSTAR_Silicon_Strip_May_2013_V2.pdf

https://drupal.star.bnl.gov/STAR/system/files/aschmah_eSTAR_Forward_Tracking_ULCA_8_2013_V4.pdf

Occupancy

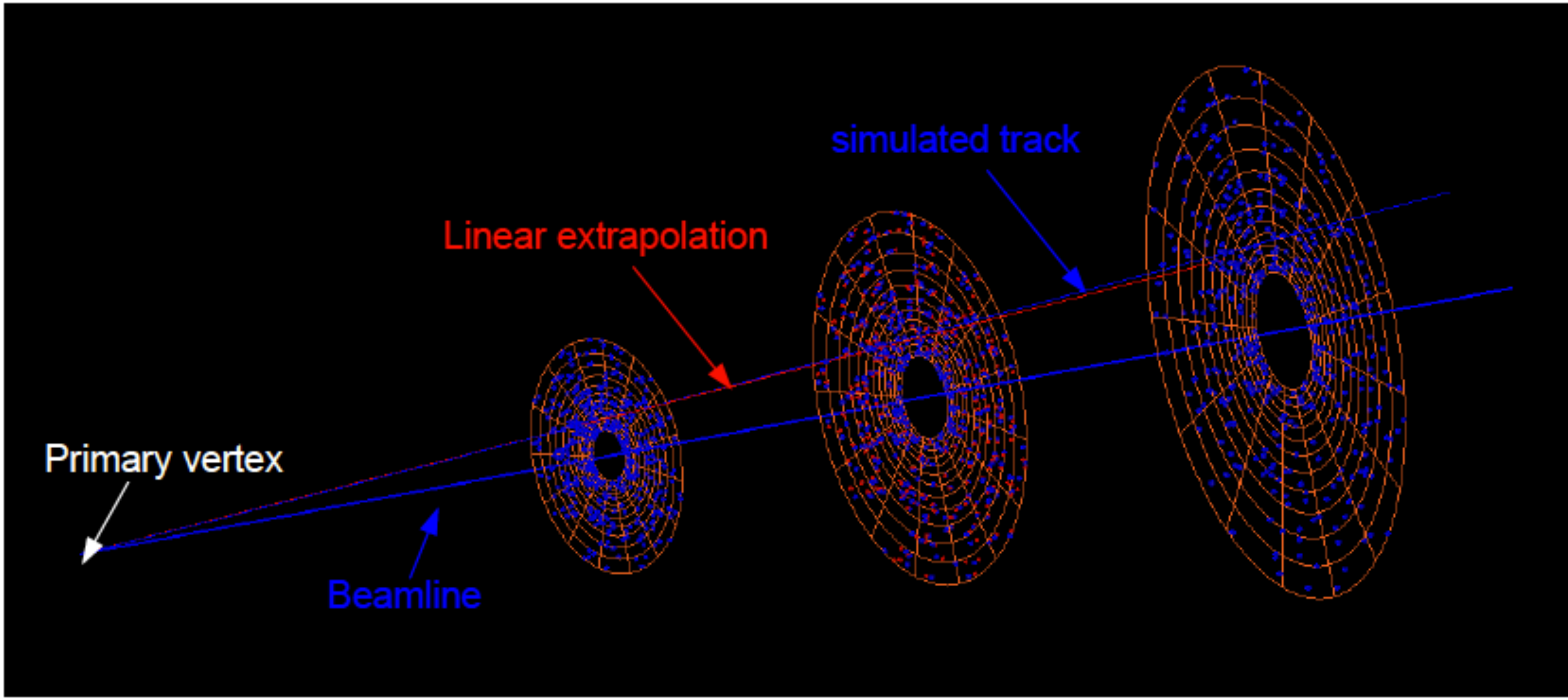


Assume total track=2*primary tracks:

Occupancy ≤ 5% (inner)
10% (outer)

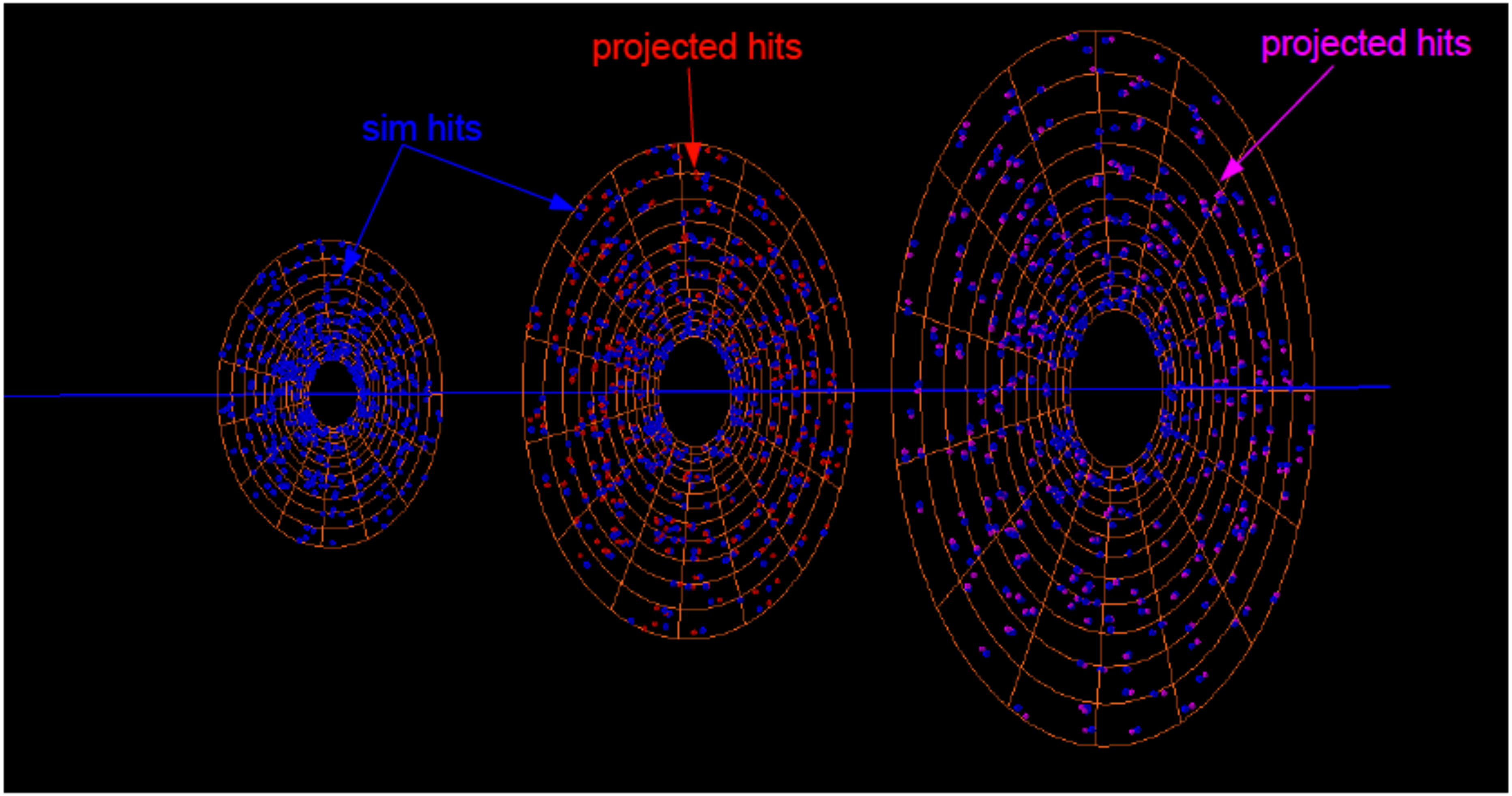
for 0-3% Au+Au collisions at 200 GeV

Hit Matching: 2nd Plane



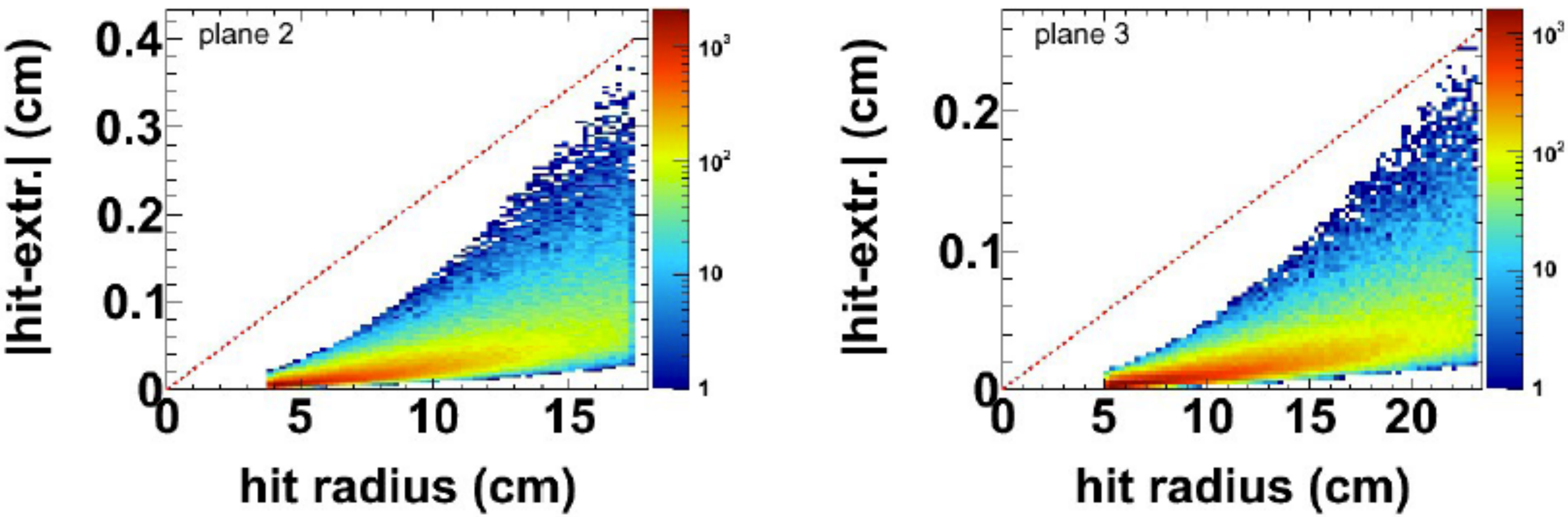
- First step: Simple hit matching for tracking
- Linear projection from primary vertex, first hit point to 2nd plane
- Red: linear extrapolation (tracks and hits points)
- Blue: simulated tracks and hit points

Hit Matching: 3rd Plane



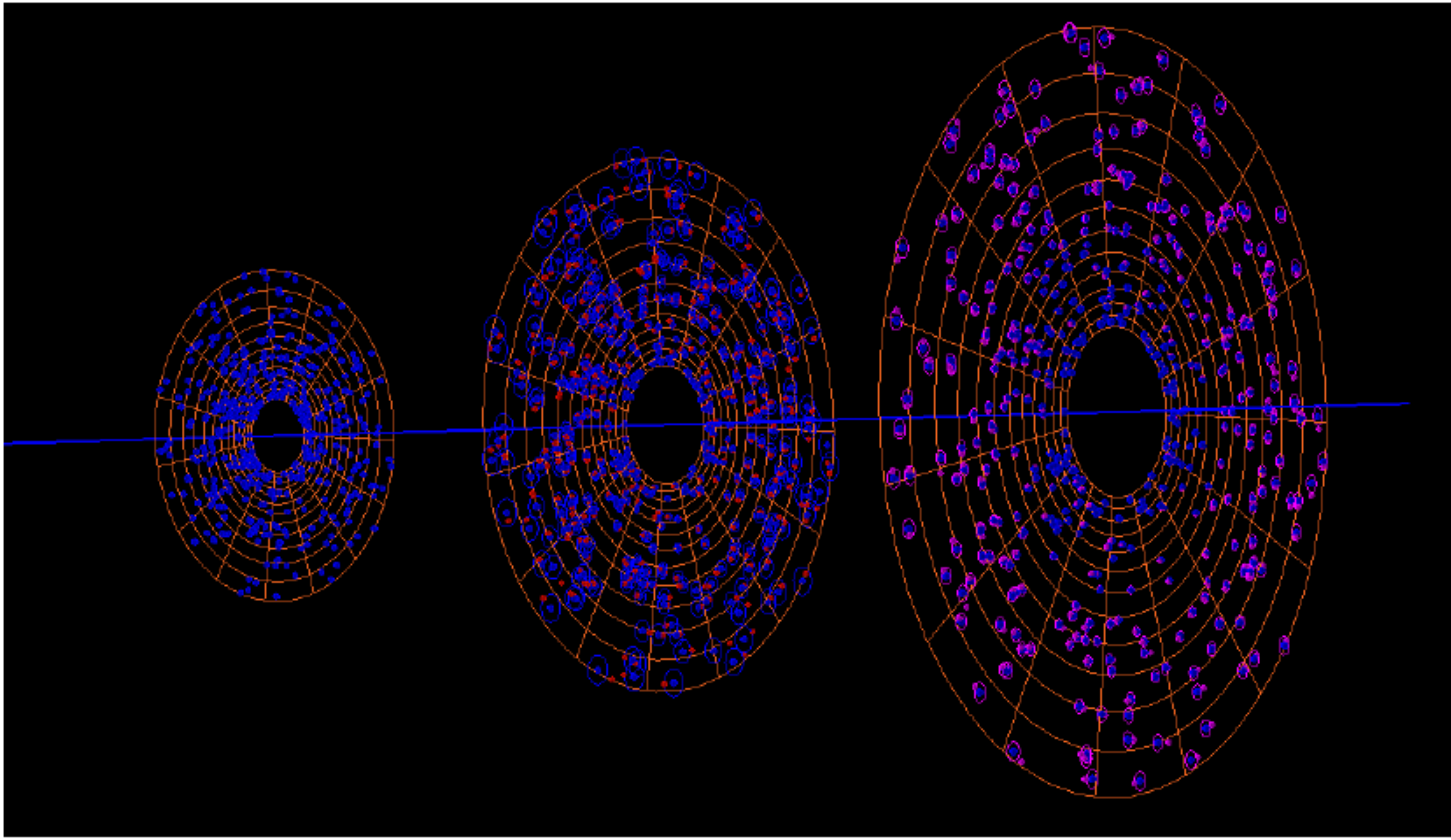
- Linear extrapolation from first and second plane to third plane (magenta hit points)
- Blue: simulated hit points

Hit Matching



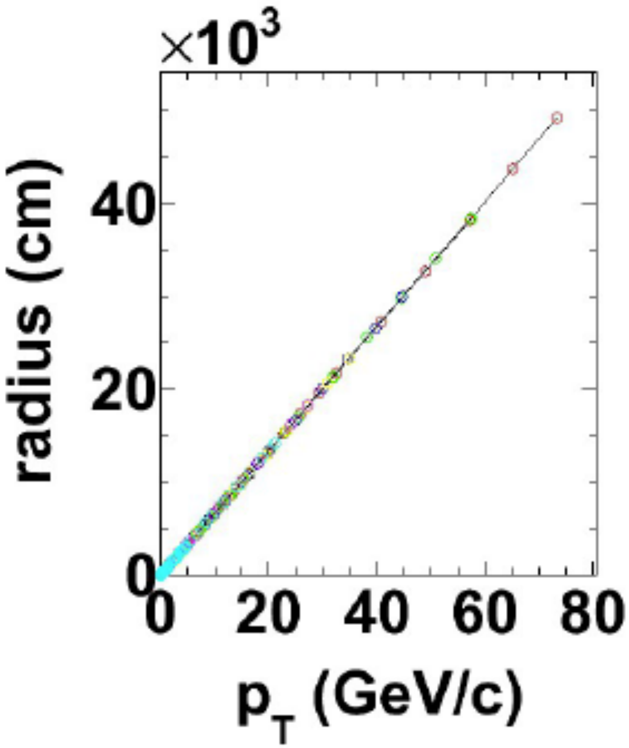
- Distance to linear extrapolations calculated for 2nd and 3rd plane
  → distance between blue and red/magenta hit points
- 500 mb events used
- No ambiguities due to noise yet
- Red line: all hits included for hit matching window

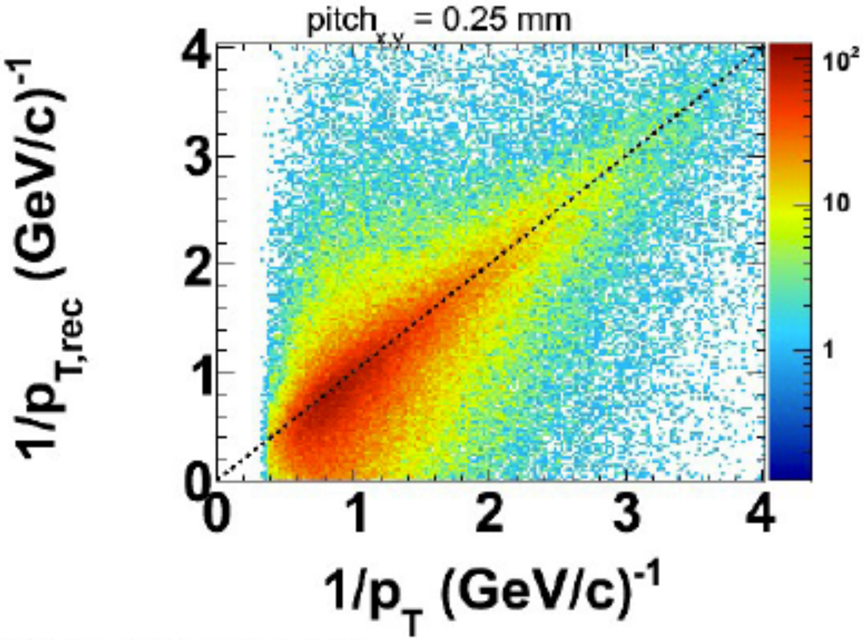
Hit Matching Windows



- Hit search radii as a function of hit radius calculated for 2nd and 3rd plane

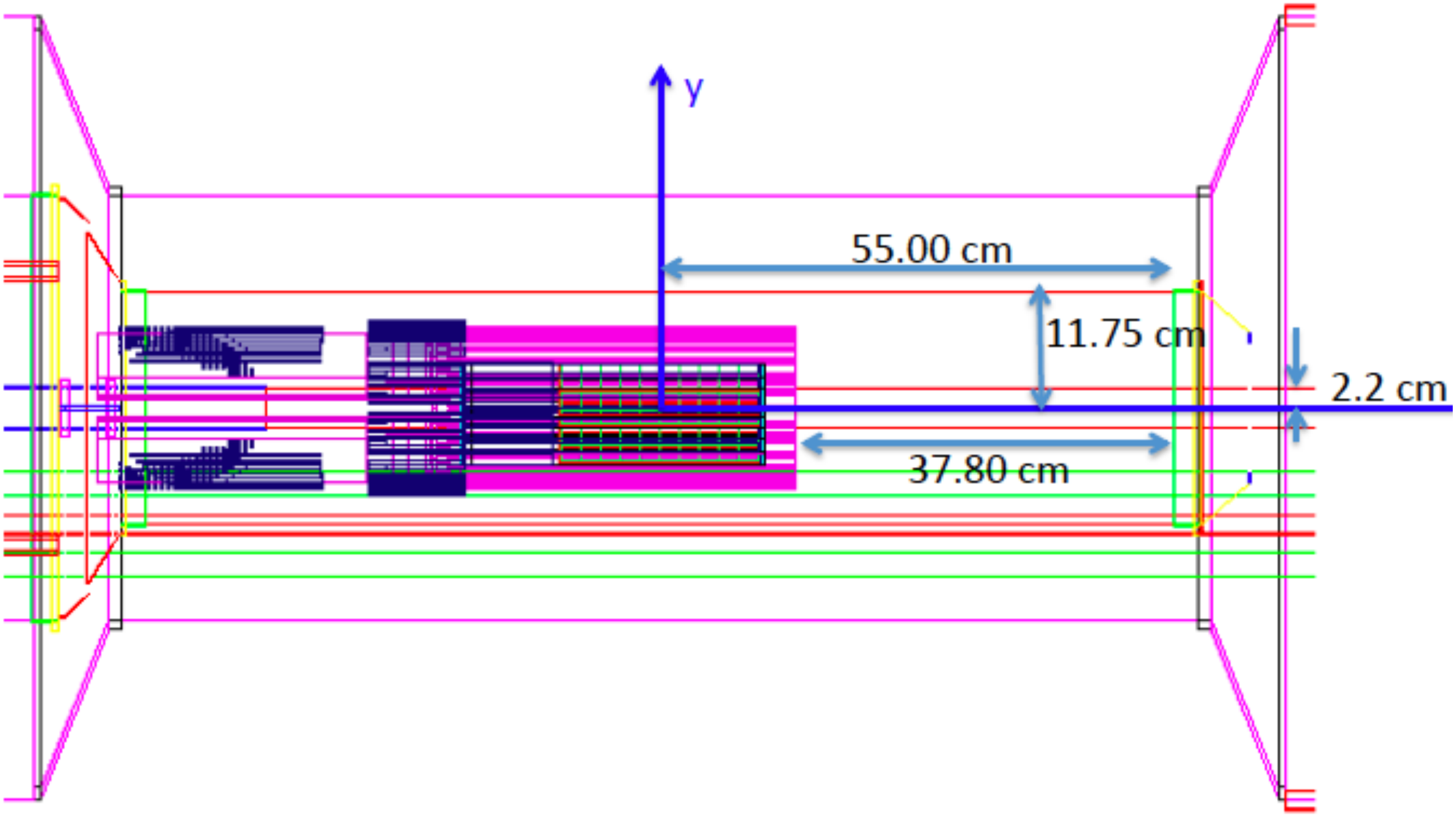
Momentum Reconstruction

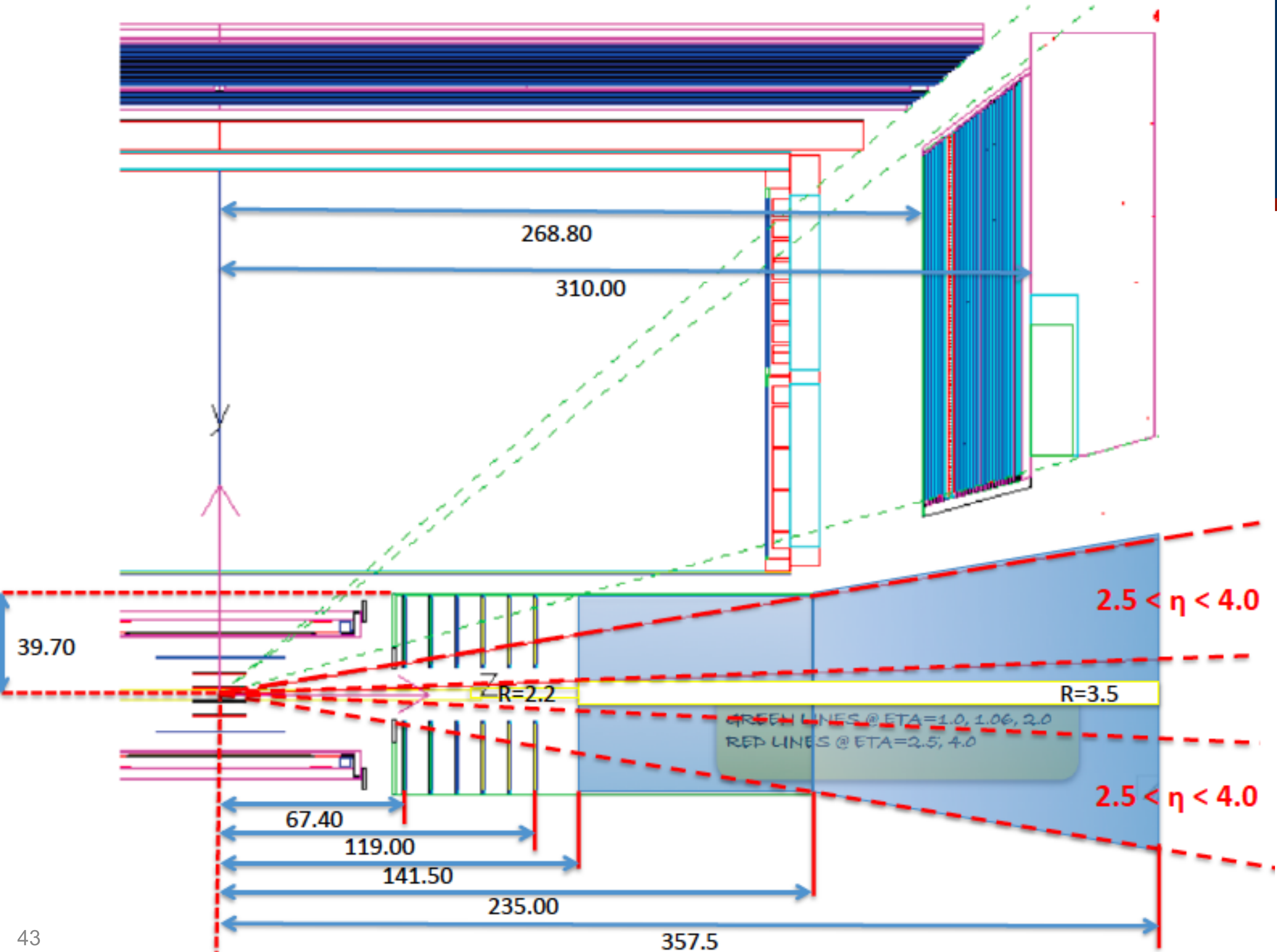




- Circle fits to hit points in transverse plane
  → linear correlation between circle radius and p_T
- Good correlation between reconstructed p_T and input p_T
- Tendency to larger reconstructed p_T values

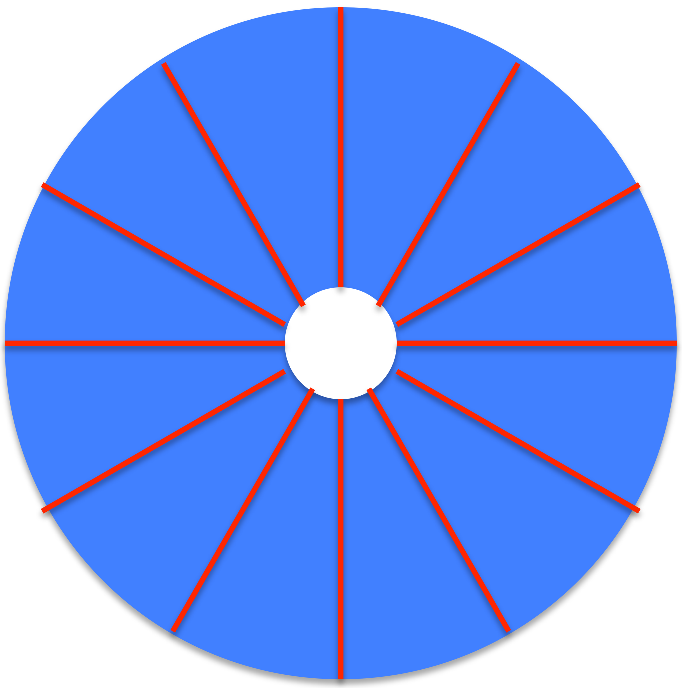
Locations




268.80
310.00
Y
Z
39.70
R=2.2
R=3.5
2.5 < η < 4.0
2.5 < η < 4.0
GREEN LINES @ ETA=1.0, 1.06, 2.0
RED LINES @ ETA=2.5, 4.0
67.40
119.00
141.50
235.00
357.5

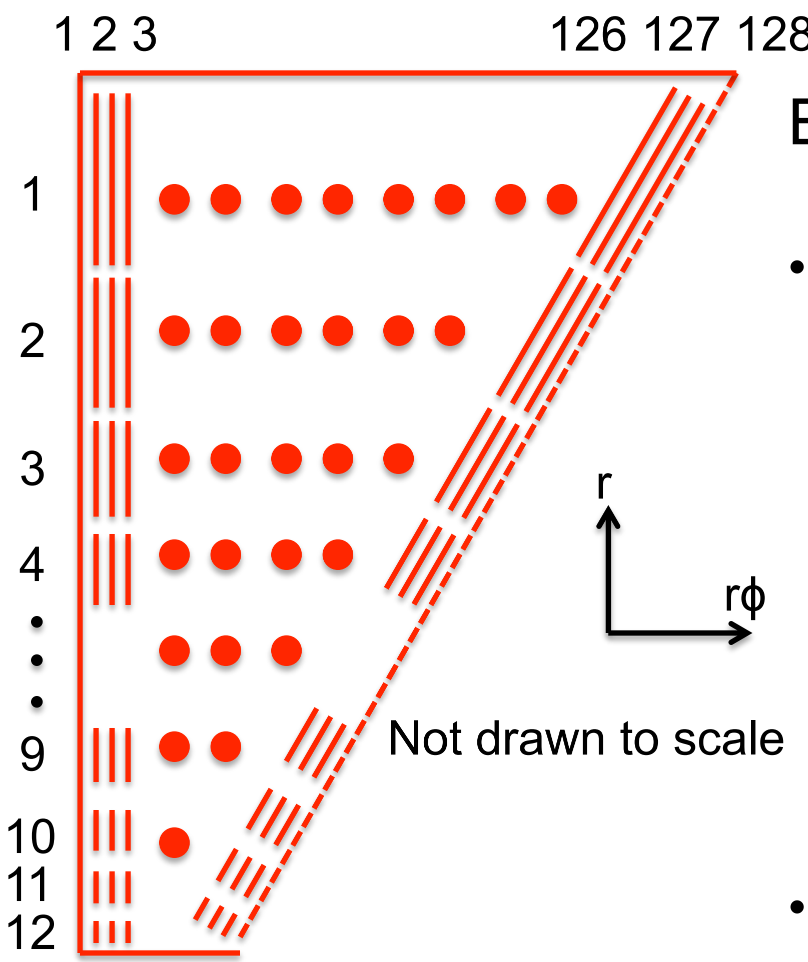
Silicon Strip Disk

- 3 Silicon strip disks at Z=70,105,140 cm
- Inner/outer radius 25/115, 38/175, 50/230mm for η=[2.5-4] coverage



Z.Ye, STAR R&D meeting, 2/10/2014

Silicon Mini-Strip Sensor



Each disk has

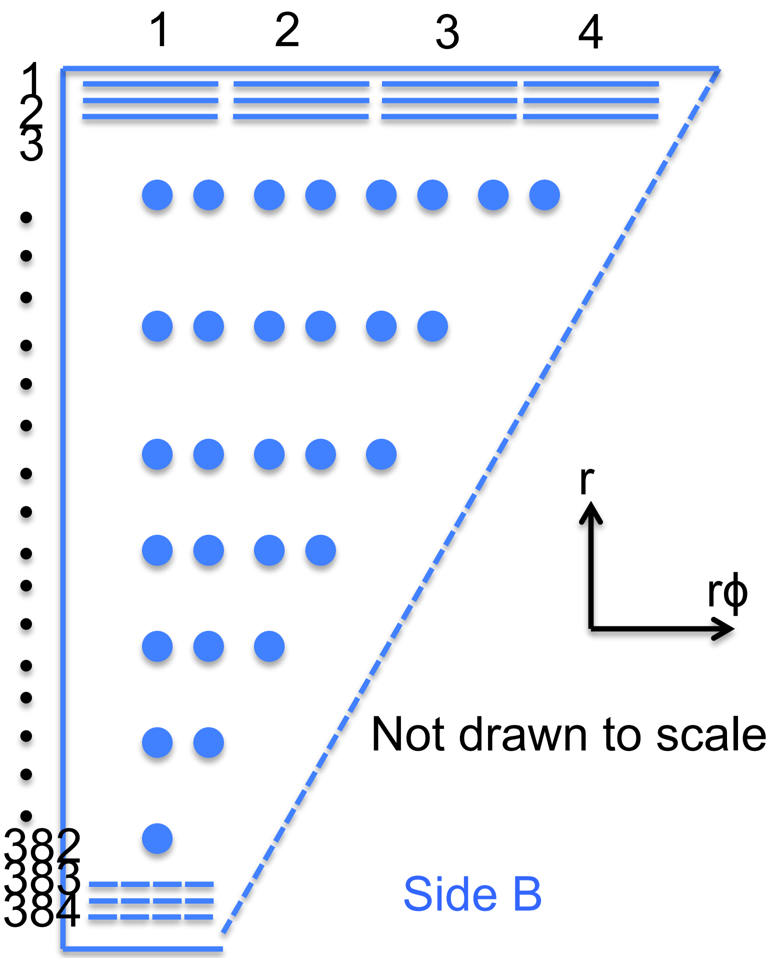
- 12 single-sided double metal silicon mini-strip sensors, with12*128 strips:

  Z=700mm
  0.11*3.4 (inner)-…-0.43*13.7 (outer)
  Z=1050mm
  0.165*5.1 (inner)-…-0.64*20.1 (outer)
  Z=1400mm
  0.22*6.8 (inner)-…-0.85*27.5 (outer)

- one disk is read out by 144 readout chips

R&D needed

Silicon Mini-Strip Sensor



Double-sided double metal silicon strip sensor, or two back-to-back single-sided double metal silicon strip sensors, with 12*128 strips on one side and 384*4 strips on the other side:

Z=700mm
3.4*0.11 (inner)-…-13.7*0.43 (outer)
Z=1050mm
5.1*0.165 (inner)-…-20.1*0.64 (outer)
Z=1400mm
6.8*0.22 (inner)-…-27.5*0.85 (outer)

If there is need for more precise r (η) resolution

R&D needed

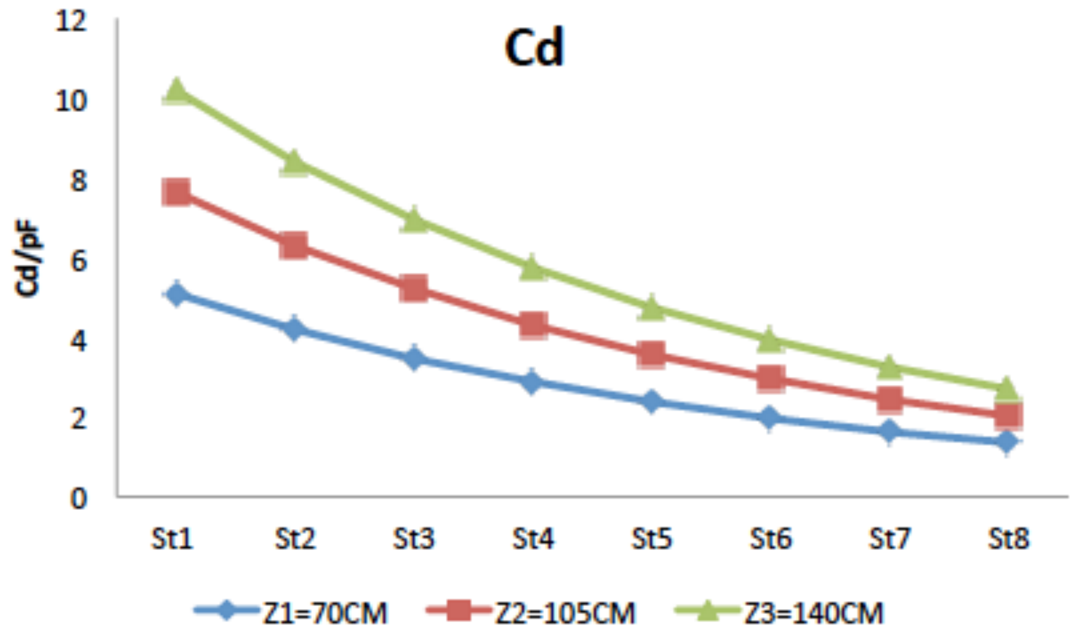
Very Rough Cost Estimation (Design/Prototype+Production)

- Detector module
  - Silicon sensor: 120+400 k
  - Front-end readout chip: 5+25 k
  - Carbon-fiber core: 50+150 k
  - Flexible Kapton PCB: 80+150 k
  - Ladder assembly: 40+240 k
- Mechanical
  - Cooling: 20+100 k
  - Mechanical Support: 50+150 k
- Readout electronics
  - Readout crate: 20+100 k
  - Sensor bias power supply: 10+100 k
  - Readout boards: 50+120 k
  - Cables: 20+80 k

Subject to large uncertainties

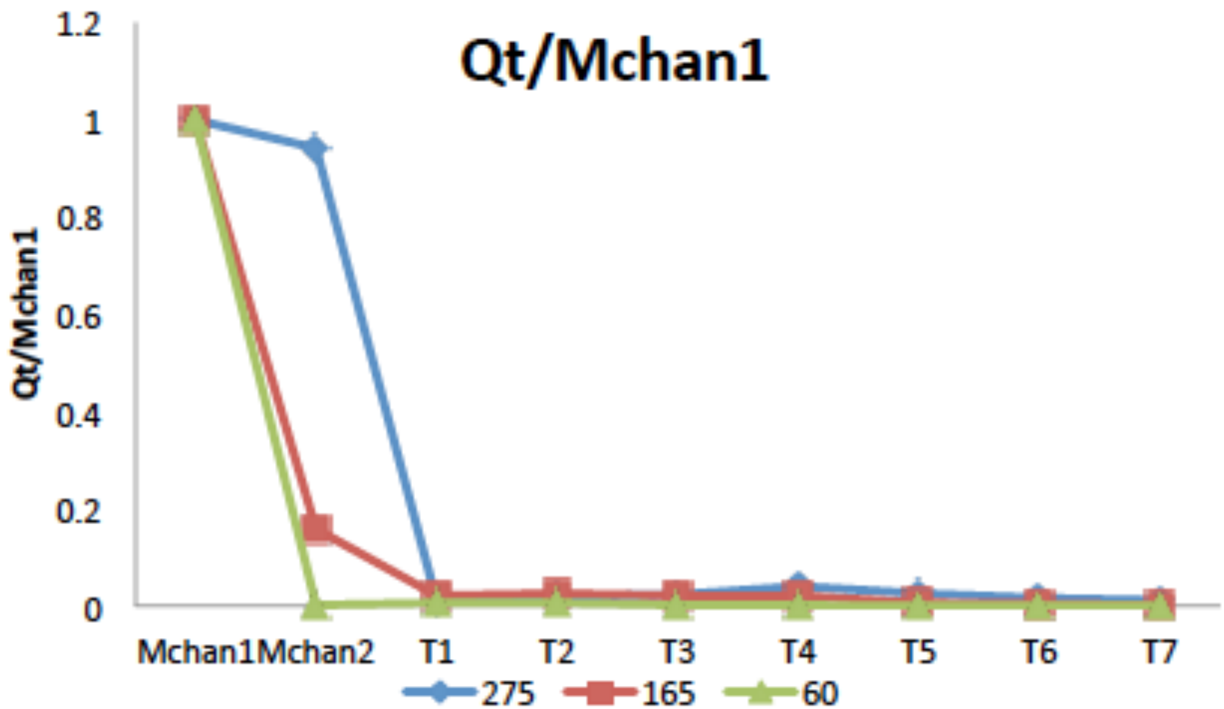
Prototyping	365-440k
Production	1745-2050k
40% contingency	840-1000k
Sum	~2970-3500k for 3 disks

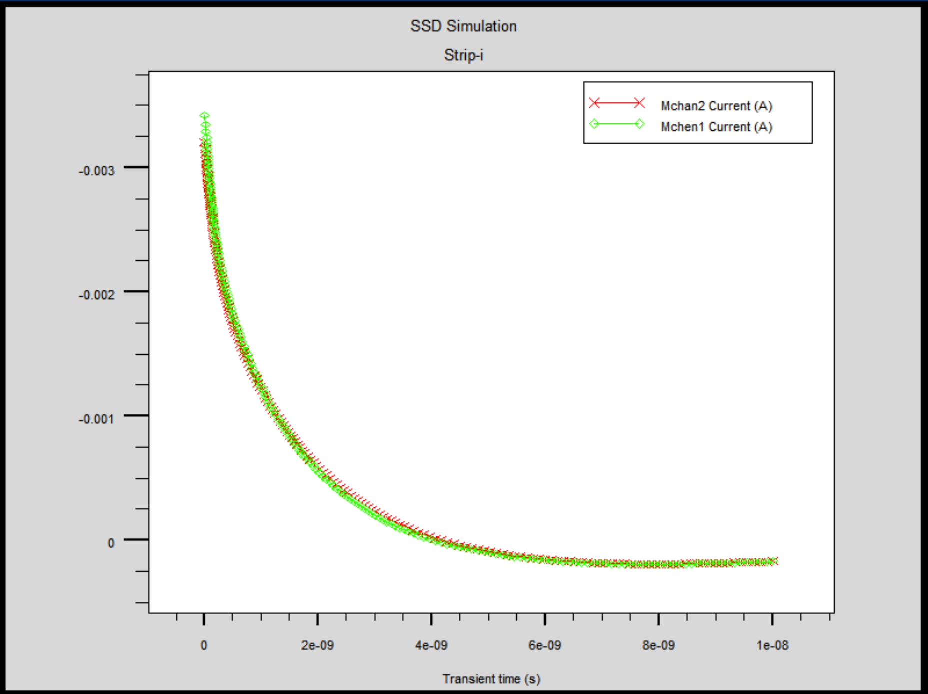
If there is need for more precise r (η) resolution



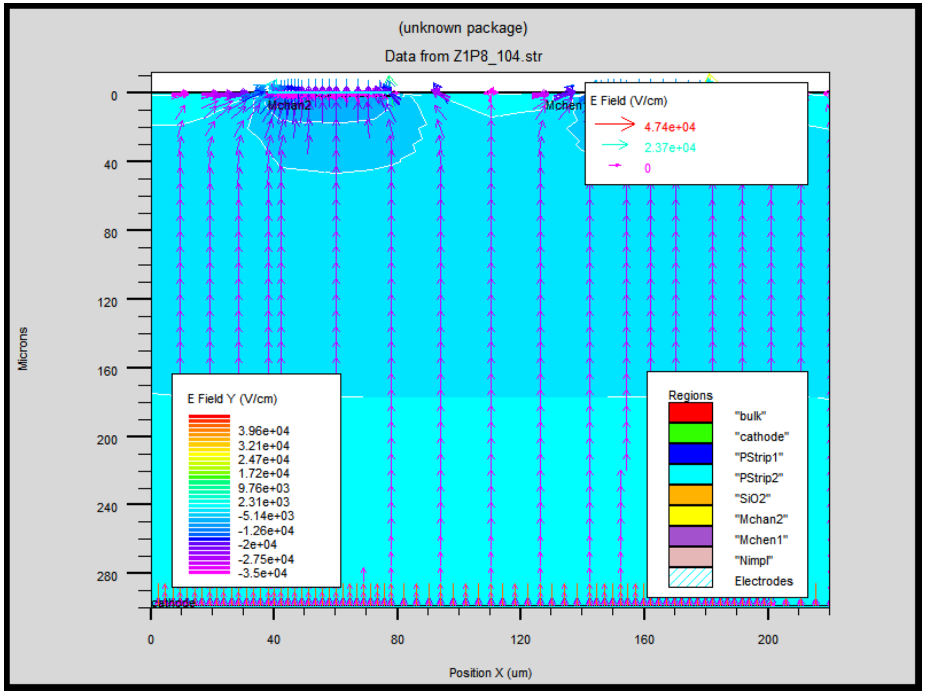
Noise = 270 +38 * Cd e$^-$
Signal = 24000 e$^-$

Sensor Characteristics from Silvaco Simulation (Babak@UIC)

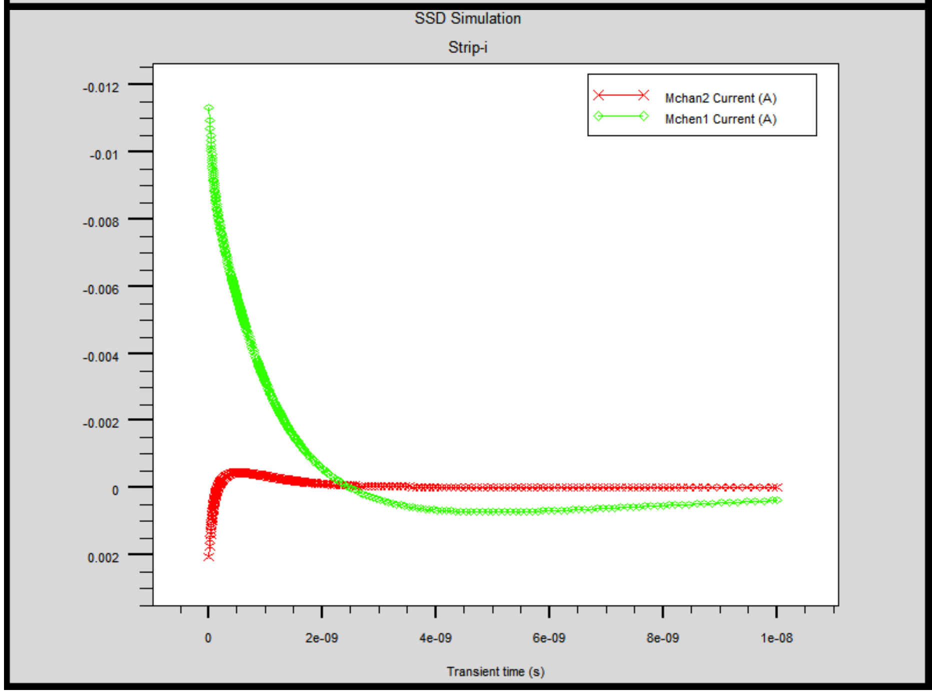




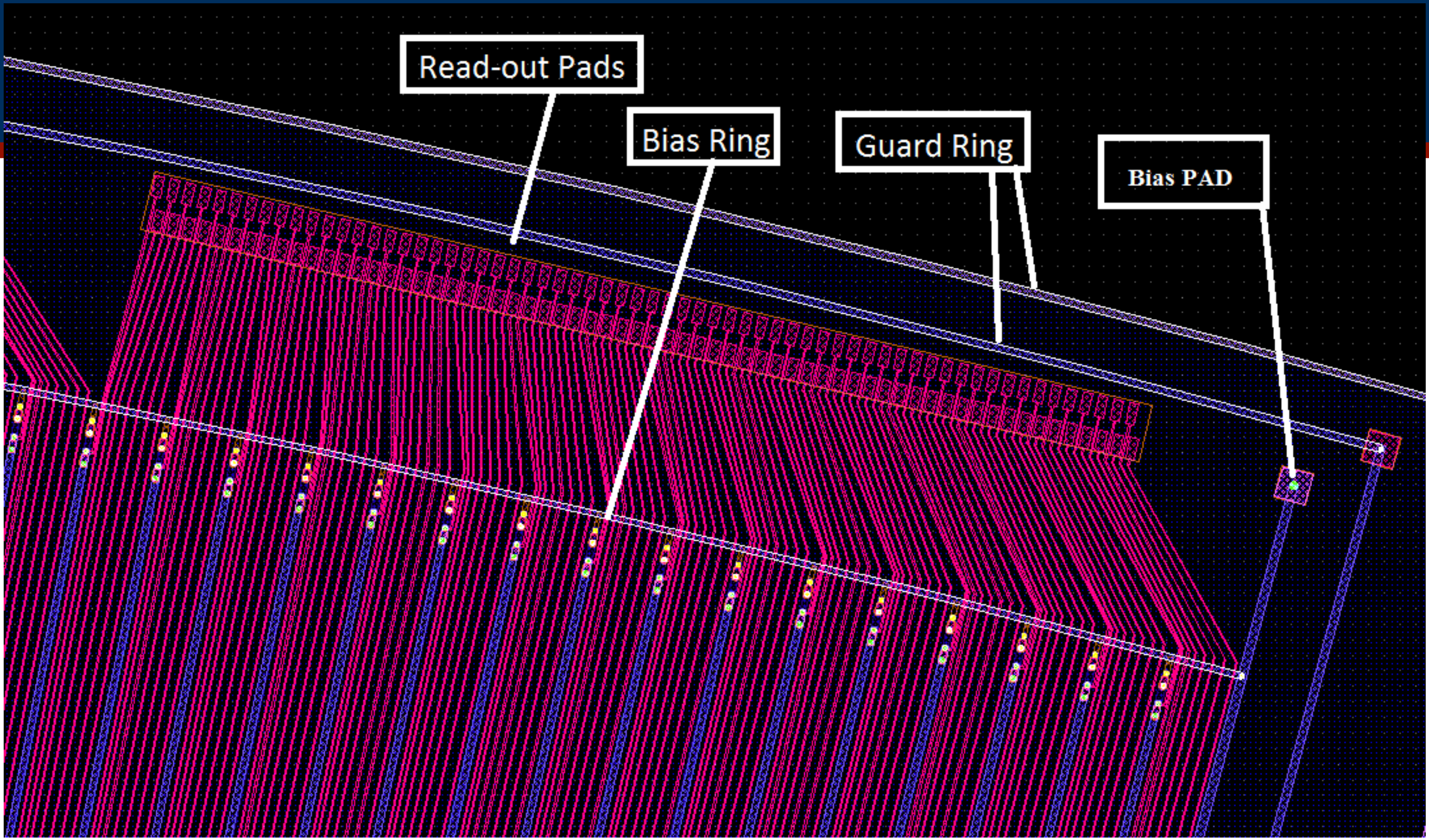
SSD Simulation
Strip-i
Mchan2 Current (A)
Mchen1 Current (A)
-0.003
-0.002
-0.001
0
0
2e-09
4e-09
6e-09
8e-09
1e-08
Transient time (s)



(unknown package)
Data from Z1P8_104.str
Microns
Position X (um)
Mchan2
E Field (V/cm)
4.74e+04
2.37e+04
0
E Field Y (V/cm)
3.96e+04
3.21e+04
2.47e+04
1.72e+04
9.76e+03
2.31e+03
-5.14e+03
-1.26e+04
-2e+04
-2.75e+04
-3.5e+04
Regions
"bulk"
"cathode"
"PStrip1"
"PStrip2"
"SiO2"
"Mchan2"
"Mchen1"
"Nimpl"
Electrodes
cathode



SSD Simulation
Strip-i
Mchan2 Current (A)
Mchen1 Current (A)
-0.012
-0.01
-0.008
-0.006
-0.004
-0.002
0
0.002
0
2e-09
4e-09
6e-09
8e-09
1e-08
Transient time (s)



Read-out Pads
Bias Ring
Guard Ring
Bias PAD